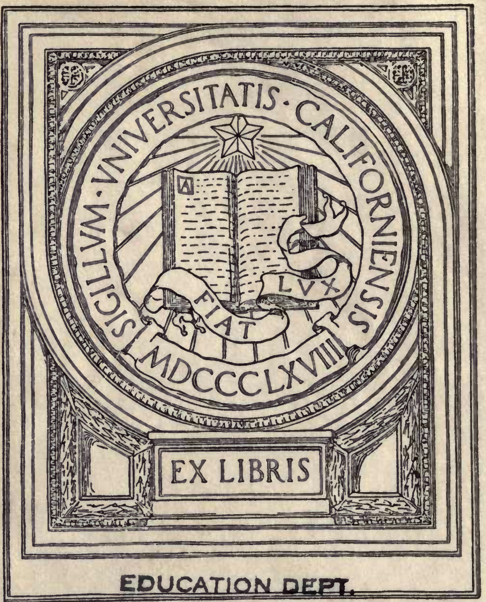

RUDIMENTS

OF

NATURAL PHILOSOPHY AND ASTRONOMY:

DESIGNED FOR THE

YOUNGER CLASSES IN ACADEMIES,

AND FOR

COMMON SCHOOLS.

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PREFACE.

Some years since, I announced to the public an intention of preparing a series of text-books, in Natural Philosophy and Astronomy, adapted, respectively, to Colleges, Academies, and Common Schools. A Treatise on Natural Philosophy in two volumes, 8vo, and a Treatise on Astronomy in one volume, 8vo, a School Philosophy, and a School Astronomy, each in a duodecimo volume, have long been before the public, and have passed through numerous editions. Various engagements have prevented my completing, until now, the original plan, by adding a work of a form and price adapted to the primary schools, and in a style so easy and familiar, as to be suited to pupils of an earlier age than my previous works.

In writing a book for the pupils of our Common Schools, or for the younger classes in Academies, I do not, however, consider myself as writing for the ignorant and uncultivated, but rather for those who have but little time for these studies, and who, therefore, require a choice selection of principles, of the highest practical utility, and desire the greatest possible amount of valuable information on the subjects of Natural Philosophy and Astronomy, in the smallest compass. The image which I have had constantly before me, is that of an intelligent scholar, of either sex, from twelve to sixteen years of age, bringing to the subject a mind improved by a previous course of studies, and a capacity of being interested in this new and pleasing department of knowledge. I have imagined the learner, after having fully mastered the principles explained in the first part, which treats of Natural Philosophy, entering upon Astronomy, in the second part, with a capacity much enlarged by what he has already acquired, and with a laudable curiosity to learn the secrets of the skies. I have imagined his teacher lending him occasional aid from a map of the stars, or a celestial globe, and stimulating as well as rewarding his curiosity, by pointing out to him the constellations. It is hoped, also, that most of the teachers who use this work, will have the still higher advantage of affording to youthful curiosity a view with which it is always delighted,—that of the moon, planets, and stars, through a telescope.

I should deem myself incompetent to write a book like the present, if I had not been, myself, a teacher, first in a common school, and afterward in an academy or grammar school of the higher order. No one, in my judgment, is qualified to write text books in any department of instruction, who does not know, by actual experience, the precise state of mind of the pupils for whom he writes. Several years of experience in teaching the rudiments of knowledge, in early life, and the education of a large family at a later period, have taught me the devices by which the minds of young learners are to be addressed, in order that subjects at once new, and requiring some powers of reflection to understand them, may be comprehended with perfect clearness, and of course with lively pleasure. Children are naturally fond of inquiring into the causes of things. We may even go farther, and say, that they begin from infancy to interrogate nature in the only true and successful mode,—that of experiment and observation. With the taper, which first fixes the gaze of the infant eye, the child commences his observations on heat and light. With throwing from him his playthings, to the great perplexity of his nurse, he begins his experiments in Mechanics, and pursues them successively, as he advances in age, studying the laws of projectiles and of rotary motion in the arrow and the hoop, of hydrostatics in the dam and the water wheel, and pneumatics in the wind-mill and the kite. I have in my possession an amusing and well-executed engraving, representing a family scene, where a young urchin had cut open the bellows to find the wind. His little brother is looking over his shoulder with innocent and intense curiosity, while the angry mother stands behind with the uplifted rod, and a countenance which bespeaks the wo that impends over the young philosopher. A more judicious parent would have gentlv reproved the error ; a more enlightened parent might have hailed the omen as indicating a Newton in disguise.

It is earnestly hoped, that the Rudiments of Natural Philosophy and Astronomy,—as much, at least, as is contained in this small volume,—will be studied in every primary school in our land. In addition to the intellectual and moral advantages, which might reasonably be expected from such a general diffusion of a knowledge of the laws of nature, and the structure of the universe, incalculable advantages would result to society from the acquaintance, which the laboring classes would thus gain, with the principles of the arts; principles which lie at the foundation of their daily operations,—for a "principle in science is a rule in art." Such a knowledge of philosophical principles, would suggest easier and more economical modes of performing the same labor; it would multiply inventions and discoveries; and it would alleviate toil by mingling with it a constant flow of the satisfaction which always attends a clear understanding of the principles of the arts.

Although this treatise is especially designed for schools, yet I would venture to recommend it to readers of a more advanced age, who may desire a concise and comprehensive view of the most important and practical principles of Natural Philosophy and Astronomy, comprising the latest discoveries in both these sciences. The part on Astronomy, especially, when compared with the sketches contained in similar works, may be found, perhaps, to have some advantages in the selection of points most important to be generally known—in perspicuity of style and arrangement—and in simplicity and fulness of illustration. It may, however, be more becoming for the author to submit this comparison to the judgment of the intelligent reader.

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PART II.

ASTRONOMY.

RUDIMENTS

OF

NATURAL PHILOSOPHY AND ASTRONOMY.

PART I.

NATURAL PHILOSOPHY.

INTRODUCTION.*

GRAND DIVISIONS OF THE NATURAL SCIENCES.

1. As in Geography we have a clearer understanding of particular countries, if we first learn the great divisions of the globe, so we shall see more fully the peculiar nature of the sciences we are now to study, if we first learn into what distinct provinces the great empire of science is divided.

To describe and classify the *external appearances* of things in nature, is the province of Natural History; to explain the *causes* of such appearances, and of all the changes that take place in the material world, is the province of Natural Philosophy. The properties of bodies which are presented to the senses, such as form, size, color, and the like, are called *external characters;* all events or occurrences in the material world, are called *phenomena.* Natural History is occupied

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[*] Instructors may find it expedient, in the case of very young learners, to pass over this Introduction, beginning at Chapter I; but when the state of the pupil is sufficiently advanced, we recommend its being well treasured up in the memory.

QUESTIONS.

ARTICLE 1. What is the province of *Natural History?* Of *Natural Philosophy?* What properties of bodies are called the *external characters?* What are *phenomena?* With what is Natural History chiefly with the external characters of bodies, which it describes and classifies; Natural Philosophy, with phenomena, which it reduces under general laws. Thus, the natural historian first observes and describes the *external characters* of animals, vegetables, and minerals, and then classifies them, by arranging such as resemble each other in separate groups. The natural philosopher, also, first observes and describes the *phenomena* of nature and art, and brings together such as are similar, under separate laws; for example, the phenomena and laws of winds, of storms, of eclipses, and of earthquakes.

2. We may form some idea of the method of classification in Natural History, and of the investigation of general principles or laws in Natural Philosophy, by taking examples in each. The individual bodies that compose the animal, the vegetable, and the mineral kingdoms, are so numerous that, in a single life, we could make but little progress in acquiring a knowledge of them, if it were not in our power to collect into large groups, such as resemble each other in a greater or less number of particulars. When this is done, our progress becomes comparatively rapid; for what we then learn respecting the group, will apply equally to all the individuals comprised in it. Hence, the various bodies in the several kingdoms of nature, are distributed into classes, orders, genera, species, and varieties. Thus, those minerals which are like each other in having a certain well-known *lustre*, are collected together into one CLASS, under the head of Metals, while others destitute of this peculiar character, but having certain other characters in common, are collected into

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chiefly *occupied?* Ditto Natural Philosophy? Give an example of the objects of the Natural Historian. Also of the Natural Philosopher.

2. Why is it necessary to *classify* the productions of nature? How does such a classification make our progress more rapid? Into what are the various bodies in nature *distributed?*

another class, under the head of Earths.* But some metals, as lead and iron, easily rust, while others, as gold and silver, do not rust at all. Hence, metals are distributed into two ORDERS; those which easily corrode being called *base* metals, and those which do not corrode, *noble* metals. But the members of each order have severally distinctive properties, which give rise to a further division of an order into GENERA. Thus, iron constitutes one genus and lead another, of the order of base metals. But of each of these genera there are several sorts, as wrought iron and cast iron, white lead and red lead. Each genus, therefore, is subdivided into SPECIES, by grouping together such members of the same genus as resemble each other in several particulars. Finally, the individuals of each species may differ from each other, and hence the species is still further divided into VARIETIES. Thus, Swedes iron and Russia iron, are varieties of the same species of the genus wrought iron, of the order of base metals.

3. The knowledge we gain of any individual body, depends upon the extent to which we carry the classification of it. It is something to ascertain the *class* to which it belongs; for example, that the body is a metal and not an earth. It is still more to learn to what *order* of metals it belongs, as that it is one of the base and not one of the noble metals. We have advanced still further when we have ascertained that it belongs to the *genus* iron, and not to that of lead. If we find that it is wrought and not cast iron, we ascertain the species; and, finally, if we learn that it is

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* This example is given merely for the purpose of illustrating the *method* of classification, and not of showing the classification of minerals as actually adopted. This would be too technical for our present purpose.

Give an example of classification in the case of *minerals*.

3. Upon what does the knowledge we acquire of any individual body depend? Show how we proceed from the *class* to the *order*, from the order to the *genus*, from the genus to the *species*, and from the species to the *variety*.

Swedes and not Russia wrought iron, we determine the variety. In regard to a body newly discovered, whether an animal, plant, or mineral, we may generally discover very readily to what class and order it belongs, but it is usually more difficult to determine its exact species or variety.

4. A clear understanding of the method of classification employed in Natural History, will aid us in learning the method of determining general principles, or laws, in Natural Philosophy. *A law is the mode in which the powers of nature act;* and this is determined by the comparison of a great number of particular cases. Thus, when we have examined the directions of rays of light under a great variety of circumstances, and always found them to be in straight lines, we say it is a law of light to move in straight lines. Laws are more or less extensive, according to the extent of phenomena they embrace. Thus, it is a law of the magnet that it attracts *iron:* it is a more extensive law (that of gravitation) that all bodies attract each other.

5. The proper method of investigating any subject in Natural Philosophy, is, first, to examine with great attention all the *facts* of the case; secondly, to *classify* these, by arranging under the same heads, such as relate to the same things; and, thirdly, to state the *conclusions* to which such a comparison of the phenomena leads us. These conclusions constitute the laws of that subject. Thus, if we apply heat to various bodies, and measure them before and after heating, we find in all cases that their size is enlarged. Hence we derive the law, that *heat expands all bodies.* If we expose solid bodies to a certain degree of heat,

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4. What is a *law?* How is it determined? How exemplified in the case of *light?* Show that laws may be more or less extensive.

5. What is the proper *method of investigating* any subject in Natural Philosophy? What is the *first step?*—the *second?*—*third?*—What do the conclusions *constitute?* Give an example in the case of *heat.*

they melt or become liquid, and liquids again are changed in the same way to vapor. Having observed these effects in a great number of individual cases, we lay it down as a law, that *heat changes solids to fluids and fluids to vapors.* By similar inquiries we ascertain all the laws of heat, which we perceive are, according to our definition, (Art. 4,) nothing more than the modes in which heat acts on various bodies. Laws or general principles like these, under one or another of which all the phenomena of the material world are reduced, constitute the elements of Natural Philosophy.

6. The laws of nature, when once learned, are applied to the explanation of the phenomena of nature or art, by a process somewhat similar to that of classification in Natural History. It would afford a partial explanation of the motion of a steamboat on the water, to refer it to the general law of elastic force, which steam has in common with air, and several other natural agents; but it would be a more complete explanation to assign the particular mode in which the force acts upon the pistons, wheels, and other parts of the machinery. *Science* is a collection of general principles or laws: *Art,* a system of rules founded on them. Arithmetic, so far as it explains the properties of numbers, is a science: so far as it furnishes rules for the solution of problems, or for calculation, it is an art. A principle in science, therefore, is a rule in art.

7. The term "Natural Philosophy" originally signified, the study of nature in general. But as the objects

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What constitute the *elements* of Natural Philosophy?

6. How are the laws of nature applied to the *phenomena of nature and art?* What would be a *partial* explanation of the motion of a steamboat? What would be a more *complete* explanation? Distinguish between *science* and *art.* How far is arithmetic a science, and how far an art? What relation have the *principles of science* to the *rules of art?*

7. What did the term Natural Philosophy *originally* signify?

that fell under its notice were multiplied, the field became too vast for one mind, and it was divided into two parts—what related to the earth belonged to Natural Philosophy, while the study of the heavenly bodies was erected into a separate department under the head of Astronomy. By and by, however, the whole of terrestrial nature, as the objects of inquiry were further multiplied, presented too wide a field for one mind to explore, and Natural Philosophy was restricted to the investigation of the *laws* of nature, while the description and classification of the productions of the several kingdoms of nature, were assigned to a distinct department under the name of Natural History. Still, it was a work too vast to take note of all the *phenomena* of nature and art, and investigate all the *laws* that govern them, and hence Natural Philosophy was again divided into Mechanical Philosophy and Chemistry. Mechanical Philosophy relates to the phenomena and laws of *masses* of matter; Chemistry, to the phenomena and laws of *particles* of matter. Mechanical Philosophy considers those effects only which are not attended by any change of nature, such as change of place, (or motion,) change of figure, and the like. Chemistry considers those effects which result from the action of the particles of matter on each other, and which more or less change the nature of bodies, so as to make them something different from what they were before. Finally, it became too much for one class of laborers to investigate the changes of nature or constitution, which are constantly going on in every body in nature, and in every process, natural or artificial, and Chemistry was, therefore, restricted to

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Why was it divided into *two parts?* What belonged to Natural Philosophy? What to Astronomy? How was Natural Philosophy still further divided? To what was it restricted? What was assigned to Natural History? Into what was Natural Philosophy again divided? To what does *Mechanical Philosophy* relate? What *Chemistry?* What *effects* does Mechanical Philosophy consider? What Chem-

inanimate matter, while what relates to *li*[illegible] was erected into a separate department under [illegible] of Physiology.

8. Natural History, moreover, found for itself an empire too vast, in attempting to describe and classify the external appearances of all things in nature. Hence this study has been successively divided into various departments, the study of vegetables being referred to Botany; of animals to Zoology; of inanimate substances to Mineralogy. Still further subdivisions have been introduced into each of these branches of Natural History, as the objects embraced in it have multiplied. Thus, the study of that branch of Zoology which relates to fishes, has been erected into a separate department under the head of Ichthyology; of birds into Ornithology; and of insects into Entomology.

9. A division of the studies which relate to the world we inhabit, has also been made into three departments, Geography, Geology, and Meteorology; all objects on the *surface* of the earth being assigned to Geography; *beneath* the surface, to Geology; and *above* the surface, to Meteorology. Of these, Geography, in this extensive signification, presents the largest field, since it comprehends, among other things, MAN and his works.

10. Mechanical Philosophy is, strictly speaking, the branch of human knowledge which we now propose to learn; but it still retains the original name Natural Philosophy, though in a sense greatly

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istry? How was Chemistry divided? To what restriction, and what was assigned to *Physiology*?

8. Into what has Natural History been successively divided? What was referred to *Botany*? What to *Zoology*? What to *Mineralogy*? What further subdivisions have been introduced into each of these branches?

9 Into what *three* departments has all terrestrial nature been divided? What is assigned to *Geography*?—what to *Geology*?—and what to *Meteorology*? Which presents the largest field?

stricted, compared with its ancient signification. The complete investigation of almost any subject, either of nature or art, usually, in fact, enters the peculiar province of several kindred departments of science. For example, let us follow so simple a substance as bread, from the sowing of the grain to its consumption as food, and we shall find that the successive processes involve, alternately, the principles of Mechanical Philosophy, Chemistry, and Physiology. The ploughing of the field is mechanical and not chemical, because it acts on masses of matter, and produces no change of nature in the matter on which it operates, so as to make it something different from what it was before, but merely changes its place. For similar reasons the sowing of the grain is mechanical. But now a change occurs in the nature of the seed. By the process called germination, it sprouts and grows and becomes a living plant. As this is a change which takes place between the particles of matter, and changes the nature of the body, it seems, by our definition, to belong to Chemistry, and it would do so were not the changes those of *living* matter: that brings it under the head of Physiology. All that relates to the growth and perfecting of the crop is, in like manner, physiological. The reaping, carting, and threshing the wheat, are all mechanical processes, acting as they do on masses of matter, and producing no alteration of nature, but merely a change of place. The grinding and separation of the grain into flour and bran, looks like a chemical process, because it reduces the wheat to particles, and brings out two new substances. We have, however, only changed the figure and place. The grain

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10. What is strictly *our* subject? What other name does it still retain? What is true of the complete investigation of any subject in nature or art? How exemplified in the case of *bread?* Why is the *ploughing* mechanical? Why is the *sowing* mechanical? Why is the *germination* physiological? How is it with the *reaping*, *carting*, and *threshing?* The *grinding* and manufacture into *flour?* Making the

consists of the same particles before and after grinding, and no new substance is really produced by the separation of the flour from the bran, for both were contained in the mixture, having the same nature before as after the separation. We next mix together flour, water, and yeast, to make bread, and bring it to the state of dough. So far the process is mechanical; but now the particles of these different substances begin to act on each other, by the process called fermentation, and new substances are produced, not existing before in either of the ingredients, and the whole mass becomes something of a very different nature from either of the articles of which it was formed. Here then is a *chemical* change. Next we make the dough into loaves and place them in the oven by processes which are mechanical; but again heat produces new changes among the particles, and brings out a new substance, bread, which is entirely different in its nature both from the original ingredients and from dough. This change, therefore, is chemical. Finally, the bread is taken into the mouth, masticated, and conveyed to the stomach by mechanical operations; but here it is subjected to the action of the principle of life that governs the animal system, and therefore again comes under the province of physiology.

11. The distinction between terms, which are apt to be confounded with each other, may frequently be expressed by single words or short phrases, although they may not convey full and precise definitions. The following are examples: History respects facts; Philosophy, causes; Physics, matter; Metaphysics, mind; Science, general principles; Art, rules and instruments. Physical laws are *modes* of action; moral and civil

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bread? Its *fermentation?* Forming into *loaves* and placing in the *oven?* The *baking?—eating?*—the final change in the *stomach?*

11. What does History respect? What Philosophy?—Physics?—Metaphysics?—Science?—Art? What are physical and what moral laws? What is the province of Natural, and what that of

laws, *rules* of action. The province of Natural Philosophy is the material world; that of Moral Philosophy is the soul. Mechanical effects result from change of place or figure; Chemical, from change of nature. Chemical changes respect inanimate matter; Physiological, living matter.

12. Mechanical Philosophy takes account of such properties of matter only as belong to all bodies whatsoever, or of such as belong to all bodies in the same state of solid, fluid, or aëriform. These are few in number compared with the peculiar properties of individual bodies, and the changes of nature which they produce on each other, all of which belong to Chemistry. Chemistry, therefore, is chiefly occupied with matter; Natural Philosophy, with motion. The leading subjects of Natural Philosophy are—

1. MATTER—its general properties.
2. MECHANICS—the doctrine of Motion.
3. HYDROSTATICS—the doctrine of Fluids in the form of *water*.
4. PNEUMATICS—the doctrine of Fluids in the form of *air*.
5. METEOROLOGY—the Atmosphere and its phenomena.
6. ACOUSTICS—the doctrine of Sound.
7. ELECTRICITY.
8. MAGNETISM.
9. OPTICS—the doctrine of Light.

Moral Philosophy? From what do mechanical effects result?—from what chemical? What do chemical changes respect, and what physiological?

12. Of what properties does Mechanical Philosophy take account? With what is chemistry chiefly occupied?—with what is Natural Philosophy? Enumerate the leading subjects of Natural Philosophy.

CHAPTER I.

GENERAL PROPERTIES OF MATTER.

EXTENSION AND IMPENETRABILITY—DIVISIBILITY—POROSITY—COMPRESSIBILITY—ELASTICITY—INDESTRUCTIBILITY—ATTRACTION.

13. All matter has at least two properties—Extension and Impenetrability. The smallest conceivable portion of matter occupies some portion of space, and has length, breadth, and thickness. Extension, therefore, belongs to all matter. Impenetrability is the property by which a portion of matter excludes all other matter from the space which it occupies. Thus, if we drop a bullet into water, it does not penetrate the water, it *displaces* it. The same is true of a nail driven into wood. These two properties of matter are all that are absolutely essential to its existence; yet there are various other properties which belong to matter in general, or at least to numerous classes of bodies, more or less of which are present in all bodies with which we are acquainted. Such are Divisibility, Porosity, Compressibility, Elasticity, Indestructibility, and Attraction. Matter exists in three different states, of solids, liquids, and gases. These result from its relation to heat; and the same body is found in one or the other of these states, according as more or less heat is combined with it. Thus, if we combine with a mass of ice a certain portion of heat, it passes from the solid to the liquid state, forming water; and if we add to water a certain other portion of heat, it passes into the same state as air, and becomes steam. Chemistry makes known to us a great number of bodies in

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13. What are the two *essential* properties of matter? Why does extension belong to all matter? Define impenetrability, and give an example. What other properties belong to matter? In what three different states does matter exist? How exemplified in wa-

the aëriform state, called *gases*, arising from the union of heat with various kinds of matter. The particles which compose water, for example, are of two kinds, oxygen and hydrogen, each of which, when united with heat, forms a peculiar kind of air or gas.

14. *Matter is divisible into exceedingly minute parts.* A leaf of gold, which is about three inches square, weighs only about the fifth part of a grain, and is only the 282,000th part of an inch in thickness. Soap bubbles, when blown so thin as to display their gaudy colors, are not more than the 2,000,000th of an inch thick; yet every such film consists of a vast number of particles. The ultimate particles of matter, or those which admit of no further division, are called *atoms*. The atoms of which bodies are composed are inconceivably minute. The weight of an atom of lead is computed at less than the three hundred billionth part of a grain. Animalcules (insects so small as to be invisible to the naked eye, and seen only by the microscope) are sometimes so small that it would take a million of them to amount in bulk to a grain of sand; yet these bodies often have a complete organization, like that of the largest animals. They have numerous muscles, by means of which they often move with astonishing activity; they have a digestive system by which their nutriment is received and applied to every part of their bodies; and they have numerous vessels in which the animal fluids circulate. What must be the dimensions of a particle of one of these fluids!

15. *A large portion of the volume of all bodies consists of vacant spaces, or pores.* Sponge, for example, exhibits its larger pores distinctly to the naked eye.

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ter? What are bodies in the state of air called? What agent maintains matter in the state of gas?

14. *Divisibility.*—Examples in gold leaf—soap bubbles. What are atoms?—weight of an atom of lead? What are animalcules? Show the extreme minuteness of their parts

But it also has smaller pores, of which the more solid matter of the sponge itself is composed, which are usually so small as to be but faintly discernible to the naked eye. The cells which these parts compose are separated by a thin fibre, which itself exhibits to the microscope still finer pores; so that we find in the same body several distinct systems of pores. Even the heaviest bodies, as gold, have pores, since water, when enclosed in a gold ball and subjected to strong pressure, may be forced through the sides. Most animals and vegetables consist in a great degree of matter that is exceedingly porous, leaving abundant room for the peculiar fluids of each to circulate. Thus, a thin slip or cross section of the root or small limb of a tree, exhibits to the microscope innumerable cells for the circulation of the sap.

16. *All bodies are more or less compressible, or may be reduced by pressure into a smaller space.* Bodies differ greatly in respect to this property. Some, as air or sponge, may be reduced to a very small part of their ordinary bulk, while others, as gold and most kinds of stone, yield but little to very heavy pressures. Still, columns of the hardest granite are found to undergo a perceptible compression when they are made to support enormous buildings. Water and other liquids strongly resist compression, but still they yield a little when pressed by immense forces.

17. *Many bodies, after being compressed or extended, restore themselves to their former dimensions, and hence are called elastic.* Air confined in a bladder, a sponge compressed in the hand, and India-rubber drawn out, are familiar examples of elastic bodies. If we drop

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15. *Porosity.*—Example in sponge. What proof is there that gold is porous? How do we learn that animal and vegetable matter is porous?

16. *Compressibility.*—How do bodies differ in this respect? What bodies easily yield to pressure?—what yield little? How is it with granite?—with water?

on the floor a ball of yarn, or of ivory or glass, it rebounds, being more or less elastic ; whereas, if we do the same with a ball of lead, it falls dead without rebounding, and is therefore non-elastic. When a body perfectly recovers its original dimensions, it is said to be *perfectly elastic*. Thus, air is perfectly elastic, because it completely recovers its former volume, as soon as the compressing force is removed, and hence resists compression with a force equal to that which presses upon it. Wood, when bent, seeks to recover itself on account of its elasticity ; and hence its use in the bow and arrow, the force with which it recovers itself being suddenly imparted to the arrow through the medium of the string.

Fig. 1.

18. *Matter is wholly indestructible.* In all the changes which we see going on in bodies around us, not a particle of matter is lost ; it merely changes its form ; nor is there any reason to believe that there is now a particle of matter either more or less than there was at the creation of the world. When we boil water and it passes to the invisible state of steam, this, on cooling, returns again to the state of water, without the least loss ; when we burn wood, the solid matter of which it is composed passes into different forms,

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17. *Elasticity.*—Give examples. Show the difference between balls of ivory and lead. When is a body *perfectly* elastic ? Give an example. Explain the philosophy of the bow and arrow.

18. *Indestructibility.*—Is matter ever annihilated or destroyed ? What becomes of water when boiled, and of wood when burned ?

some into smoke, some into different kinds of airs, or gases, some into steam, and some remains behind in the state of ashes. If we should collect all these various products, and weigh them, we should find the amount of their several weights the same as that of the body from which they were produced, so that no portion is lost. Each of the substances into which the wood was resolved, is employed in the economy of nature to construct other bodies, and may finally reappear in its original form. In the same manner, the bodies of animals, when they die, decay and seem to perish ; but the matter of which they are composed merely passes into new forms of existence, and reappears in the structure of vegetables or other animals.

19. *All matter attracts all other matter.* This is true of all bodies in the Universe. In this extensive sense, attraction is called *Universal Gravitation.* In consequence of the attraction of the earth for bodies near it, they fall toward it, and this kind of attraction is called *Gravity.* Several distinct cases of this property occur also among the particles of matter. That which unites particles of the same kind (as those of a musket ball) in one mass, is called *Aggregation ;* that which unites particles of different kinds, forming a compound, (as the particles of flour, water, and yeast in bread,) is *Affinity.* The term *Cohesion* is used to denote simply the union of the separate parts that make up a mass, without considering whether the particles themselves are simple or compound. Thus the *grains* which form a rock of sandstone, are united by cohesion. Magnetism and electricity also severally endue different portions of matter with tendencies either to attract or repel each other, which are called,

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What becomes of the bodies of animals when they die ?

19. *Attraction.*—How extensive ? What is it called when applied to all the bodies in the universe ? Why do bodies fall toward the earth ? What is this kind of attraction called ? What is aggregation ?—affinity ?—cohesion ? Give an example of each. What are

respectively, *Magnetic* and *Electric* attractions. *Tenacity,* or that force by which the particles of matter hang together, is only a form of cohesion. Of all known substances, iron wire has the greatest tenacity. A number of fine wires bound together constitute what is called a wire cable. These cables are of such prodigious strength that immense bridges are sometimes suspended by them. The Menai bridge, in Wales, one of the greatest works in modern times, is thus supported at a great height, although it weighs toward two thousand tons.

Fig. 2.

CHAPTER II.

MECHANICS.

MOTION IN GENERAL—LAWS OF MOTION—CENTER OF GRAVITY—PRINCIPLES OF MACHINERY.

20. MECHANICS, or the DOCTRINE OF MOTION, *is that part of Natural Philosophy which treats of the laws of equilibrium and motion.* It considers also the nature of the *forces* which put bodies in motion, or which maintain them either in motion, or in a state of rest or equilibrium. The great principles of motion are the

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magnetic and electric attractions? Define tenacity. What substance has the greatest? How employed in bridges?

20. Define mechanics. What are those agents called which put

same everywhere, being applicable alike to solids, liquids, and gases; to the most common objects around us, and to the heavenly bodies. The science of Mechanics, therefore, comprehends all that relates to the laws of motion; to the forces by which motion is produced and maintained; to the principles and construction of all machines; and to the revolutions of the heavenly bodies.

SECTION 1.—*Of Motion in general.*

21. Motion is change of place from one point of space to another. It is distinguished into real and apparent; absolute and relative; uniform and variable. In *real* motion, the moving body itself actually changes place; in *apparent* motion, it is the spectator that changes place, but being unconscious of his own motion, he refers it to objects without him. Thus, when we are riding rapidly by a row of trees, these seem to move in the opposite direction; the shore appears to recede from the sailor as he rapidly puts to sea; and the heavenly bodies have an apparent daily motion westward, in consequence of the spectator's turning with the earth on its axis to the east. *Absolute* motion is a change of place from one point of space to another without reference to any other body: *Relative* motion is a change of position with respect to some other body. Two bodies may both be in absolute motion, but if they do not change their position with respect to each other, they will have no relative motion, or will be relatively at rest. The men on board a ship under sail, have all the same absolute motion,

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bodies in motion or keep them at rest? How extensively do the great principles of motion prevail? What does the science of mechanics comprehend?

21. Define motion. Into what varieties is it distinguished? Explain the difference between real and apparent motion. Give examples of apparent motion. Distinguish between absolute and relative motion. Example in the case of persons on board a ship—

and so long as they are still, they have no other; but whatever changes of place occur among themselves, give rise to relative motions. If two persons are travelling the same way, at the same rate, whether in company or not, they have no relative motion; if one goes faster than the other, the latter has a relative motion backward equal to the difference of their rates; and if they are travelling in opposite directions, their relative motion is equal to the sum of both their motions. A body moves with a *uniform* motion when it passes over equal spaces in equal times; with a *variable* motion, when it passes over unequal spaces in equal times. If a man walks over just as many feet of ground the second minute as the first, and the third as the second, his motion is uniform; but if he should walk thirty feet one minute, forty the next, and fifty the next, his motion would be variable.

22. *Force is any thing that moves, or tends to move a body.* The strength of an animal exerted to draw a carriage, the impulse of a waterfall in turning a wheel, and the power of steam in moving a steamboat, are severally examples of a force. A weight on one arm of a pair of steelyards, in equilibrium with a piece of merchandise, although it does not move, but only *tends* to move the body, is still a force, since it would produce motion were it not counteracted by an equal force. The quantity of motion in a body is called its *momentum*. Two bodies of equal weight, as two cannon-balls, will evidently have twice as much motion as one; nor would it make any difference if they were united in one mass, so as to form a single body of twice the weight of the separate balls; the quantity of motion would be doubled by doubling the mass, while the velocity remained the same. Again, a ball that

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in the case of travellers? When does a body move with *uniform* motion? When with *variable* motion? Example.

22. Define force. Examples. What is momentum? Upon what

moves twice as fast as before, has twice the quantity of motion. Momentum therefore depends upon two things—the velocity and quantity of matter. A large body, as a ship, may have great momentum with a slow motion; a small body, as a cannon-ball, may have great momentum with a swift motion; but where great quantity of matter (or *mass*) is united with great swiftness, the momentum is greatest of all. Thus a train of cars on a railroad moves with prodigious momentum; but the planets in their revolutions around the sun, with a momentum inconceivably greater.

23. To the eye of contemplation, the world presents a scene of boundless *activity*. On the surface of the earth, hardly any thing is quiescent. Every tree is waving, and every leaf trembling; the rivers are running to the sea, and the ocean itself is in a state of ceaseless agitation. The innumerable tribes of animals are in almost constant motion, from the minutest insect to the largest quadruped. Amid the particles of matter, motions are unceasingly going forward, in astonishing variety, that are effecting all the chemical and physiological changes to which matter is constantly subjected. And if we contemplate the same subject on a larger scale, we see the earth itself, and all that it contains, turning with a steady and never ceasing motion around its own axis, wheeling also at a vastly swifter rate around the sun, and possibly accompanying the sun himself in a still grander circuit around some distant center. Hence, almost all the phenomena or effects which Natural Philosophy has to investigate and explain are connected with motion and dependent on it.

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two things does it depend? What union of circumstances produces great momentum? Example.

23. What proofs of activity do we see in nature? Give examples in the vegetable kingdom—in the animal—among the particles of matter—and among the heavenly bodies. Upon what are almost all the phenomena of Natural Philosophy dependent?

SEC. 2.—*Of the Laws of Motion.*

24. Nearly all the varieties of motion that fall within the province of Mechanical Philosophy, have been reduced to three great principles, called the Laws of Motion. We will consider them separately.

FIRST LAW.—*Every body will persevere in a state of rest, or of uniform motion in a straight line, until compelled by some force to change its state.* This law contains four separate propositions; first, that unless put in motion by some external force, a body always remains at rest; secondly, that when once in motion it always continues so unless stopped by some force; thirdly, that this motion is uniform; and fourthly, that it is in a straight line. Thus, if I place a ball on a smooth sheet of ice, it will remain constantly at rest until some external force is applied, having no power to move itself. I now apply such force and roll it; being set in motion, it would move on forever were there no impediments in the way. It will move uniformly, passing over equal spaces in equal times, and it will move directly forward in a straight course, turning neither to the right hand nor to the left. This property of matter to remain at rest unless something moves it, and to continue in motion unless something stops it, is called *Inertia.* Thus the inertia of a steamboat opposes great resistance to its getting fully into motion; but having once acquired its velocity, it continues by its inertia to move onward after the engine is stopped, until the resistance of the water and other impediments destroy its motion. The planets continue to revolve around the sun for no other reason than this, that they were put in motion and meet with nothing to stop them. Whenever a horse harnessed to a carriage starts suddenly forward, he breaks his traces,

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24. To how many great principles have all the varieties of motion been reduced? What are they called? State the first law. Enumerate the four propositions contained in this law. Example.

because the inertia of the carriage prevents the sudden motion being instantly propagated through its mass, and the force of the horse being all expended on the traces, breaks them. On the other hand, if a horse suddenly stops, when on a run, the rider is thrown over his head; for having acquired the full motion of the horse, he does not instantly lose it, but, on account of his inertia, continues to move forward after the force that put him in motion is withdrawn. This principle is pleasingly illustrated in what is called the *doubling* of the hare. A hare closely pursued by a greyhound, starts from A, and when he arrives at C, the dog is hard upon him; but the hare being a lighter animal than the dog, and having of course less inertia, turns short at C and again at E, while the dog cannot stop so suddenly, but goes further round at D and also F, and thus the hair outruns him. Put a card of pasteboard across a couple of wine glasses, and two sixpences directly over the glasses, as in the figure; then strike the edge of the card at A a smart blow, and the card will slip off and leave the money in the glasses. The coins, on account of their inertia, do not instantly receive the motion communicated to the card. If the blow, however, be gentle, all will go off together.

Fig. 3.

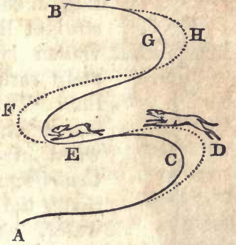
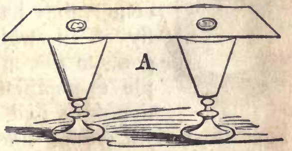


Fig. 4.



What is inertia? Example in a steamboat—in the planets—in a horse—in the doubling of a hare—and in the card and coin.

25. The first law of motion also asserts, that all moving bodies have a tendency to move in *straight lines*. We see, indeed, but few examples of such motions either in nature or art. If we throw a ball upward, it rises and falls in a curve; water spouting into the air does the same; rivers usually run and trees wave in curves; and the heavenly bodies revolve in apparent circles. Still, when we attentively examine each of these cases, and every other case of motion in curves, we find one or more forces operating to cause the body to deviate from a straight line. When such cause of deviation is removed, the body immediately resumes its progress in a straight line. This effort of bodies, when moving in curves, to proceed directly forward in a straight line, is called the *Centrifugal Force*. If we turn a grindstone, the lower part of which dips into water, as the velocity increases the water is thrown off from the rim in straight lines which touch the rim and are therefore called *tangents*[*] to it; and it is a general principle, that when bodies free to move, revolve in curves about a center, they have a constant tendency to fly off in straight lines, which are tangents to the curves. We see this principle exemplified in giving a rotary motion to a pail or basin of water. The liquid first rises on the sides of the vessel, and if the rapidity of revolution be increased, it escapes from

Fig. 5.

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[*] A line is said to be a tangent to a curve, when it touches the curve, but does not cut it.

25. Are the motions observed in the natural world, usually performed in straight or in curved lines? Why then is it said that bodies naturally move in straight lines? What is this effort to move in

the top in straight lines which are tangents to the rim of the vessel. If we pass a cord through a staple in the ceiling of a room, and bringing down the two ends, attach them to the ears of a pail containing a little water, (suspending the vessel a few feet above the floor,) and then, applying the palms of the hands to the opposite sides of the pail, give it a steady rotary motion, the water will first rise on the sides of the vessel and finally be projected from the rim in tangents. The experiment is more striking if we suffer the cord to untwist itself freely, after having been twisted in the preceding process.

26. SECOND LAW. *Motion, or change of motion, is proportioned to the force impressed, and is produced in the line of direction in which that force acts.* First, the quantity of motion, or momentum, is proportioned to the force applied. A double blow produces a double velocity upon a given mass, or the same velocity upon twice the mass. Two horses applied with equal advantage to a load, will draw twice the load of one horse. It follows also from this law, that every force applied to a body, however small that force may be, produces *some* motion. A stone falling on the earth moves it. This may seem incredible; but if we suppose the earth divided into exceedingly small parts, each weighing only a pound for example, then we may readily conceive how the falling stone would put it in motion. Now the effect is not lost by being expended on the whole earth at once; the momentum produced is the same in both cases; but in proportion as the quantity of matter is increased the velocity is diminished, and it would be as much less

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straight lines called? Example in a grindstone—in a suspended vessel of water.

26. What is the second law of motion? Show that the quantity of motion is proportioned to the force applied. Explain how the smallest force produces *some* motion.

as the weight of the whole earth exceeds one pound. It would therefore be inappreciable to the senses, but still capable of being expressed by a fraction, and therefore a real quantity. "A continual dropping wears away stone." Each drop, therefore, must contribute something to the effect, although too small to be perceived by itself.

27. Secondly, motion is produced in the line of *direction* in which the force is applied. If I lay a ball on the table and snap it with my thumb and finger, it moves in different directions according as I change the direction of the impulse; and this is conformable to all experience. A single force moves a body in its own direction, but two forces acting on a body at the same time, move it in a line that is intermediate between the two. Thus, if I place a small ball, as a marble, on the table, and at the same moment snap it with the thumb and finger of each hand, it will not move in the direction of either impulse, but in a line between the two. A more precise consideration of this case has led to the following important law:

If a body is impelled by two forces which may be represented in quantity and direction by the two sides of a parallelogram, it will describe the diagonal in the same time in which it would have described each of the sides separately, by the force acting parallel to that side.

Thus, suppose the parallelogram A B C D, represents a table, of which the side A B is just twice the length of A D. I now place the ball on the corner A, and nail a steel spring (like a piece of watch spring) to each side of the corner, so that when bent back it may be sprung upon the ball, and move it parallel to the edge of the table. I first spring each force separately, bending back that which acts parallel to the

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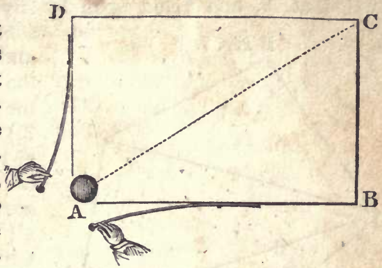
27. Show that motion is in the line of direction of the force. How does a single force move a body? How do two forces move it? Recite the law represented in figure 6, and explain the figure.

longer side so much further than the other, that the ball will move over the two sides in precisely the same time, suppose two seconds. I now let off the springs on the ball at the same instant, and the ball moves across the table, from corner to corner, in the same two seconds. It is not necessary that the parallelogram should be right-angled like a table. The effect will be the same at whatever angle the sides of the parallelogram meet.

Fig. 6.



28. If I take a triangular board instead of the table, and fix three springs at one corner, so as to act parallel to the three sides of the board, and give each spring a degree of strength proportioned to the length of the side in the direction of which it acts, and then let all those springs fall upon the ball at the same instant, the ball will remain at rest. This fact is expressed in the following proposition:

If three forces, represented in quantity and direction by the three sides of a triangle, act upon a body at the same time, it will be kept at rest.

A kite is seen to rest in the air on this principle, being in equilibrium between the force of gravity which would carry it toward the earth, that of the string, and that of the wind, which severally act in the three directions of the sides of a triangle, and

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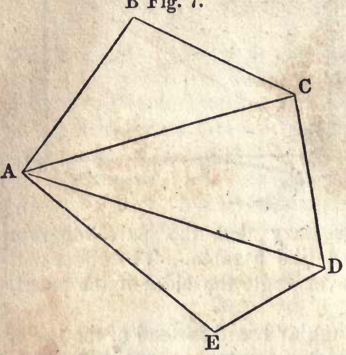
28. What is the effect of three forces, represented in quantity and direction by the three sides of a triangle? How does a kite exemplify this principle? Is the principle confined to three directions?

neutralize each other. Nor is the principle confined to *three* directions merely, but holds good for a polygon of any number of sides. For example, a body situated at A, and acted upon by five forces represented in quantity and direction by the five sides of the polygon, (Fig. 7,) would remain at rest. If the forces were only four, corresponding to all the sides of the figure except the last, EA, then the body would describe this side in the same time in which it would describe each of the sides by the forces acting separately.

Fig. 7.



29. *Simple* motion is that produced by one force; *compound* motion, that produced by the joint action of several forces. Strictly speaking, we never witness an example of simple motion; for when a ball is struck by a single impulse, although the motion is simple relatively to surrounding bodies, yet the ball is at the same time revolving with the earth on its axis and around the sun, and subject perhaps to innumerable other motions. Although all bodies on the earth are acted on at the same moment by many forces, and therefore it is difficult or even impossible to tell what is the line each describes in space under

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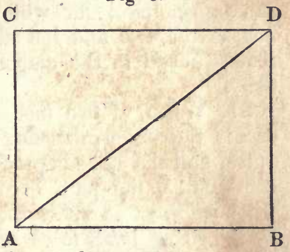
Case of a polygon of five sides. Where only four forces are applied, how will the body move ?

29. What is simple, and what compound motion ? Do we ever witness simple motions in nature ? Example. When a force is

their joint action, yet each individual force produces precisely the same change of direction in the body as though it were to act alone. If it acts in the same direction in which the body is moving, it will add its own amount; if in the opposite direction, it will subtract it; if sidewise, it will turn the body just as far to the right or left in a given time, as it would have done had it been applied to the body at rest. Thus, if while a body is moving from A to B, (Fig. 8,) it be struck by a force in the direction of AC, it will reach the line CD, in the same time in which it would have done had it been subject to no other force. It will, however, reach that line in the point D instead of C. When a man walks the decks of a ship under sail, his motions are precisely the same with respect to the other objects on board, as though the ship were at rest; but the line which he actually describes under the two forces is very different.

Fig. 8.



30. Instances of this diagonal motion are constantly presented to our notice. In crossing a river, the boat moves under the united impulses of the oars and the current, and describes the diagonal whose sides are proportional to the two forces respectively. Equestrians sometimes exhibit feats of horsemanship by leaping upward from the horse while running, and recovering their position again. They have, in fact,

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applied to a body in motion, what is the effect? Explain from Fig 8. Case of a man walking the deck of a ship.

30. Examples of diagonal motion. A boat crossing a river—Equestrians—Two men in a boat tossing a ball—Rowing.

only to rise and fall as they would do were the horse at rest; for the forward motion which the rider retains by his inertia, during the short interval of his ascent and descent, carries him onward, so that he rises in one diagonal and falls in another. Two men sitting on opposite sides of a boat in rapid motion, will toss a ball to each other in the same manner as though the boat were at rest; but the actual movement of the ball will be diagonal. Rowing, itself, exemplifies the same principle; for while one oar would turn the boat to the left and the other to the right, it actually moves ahead in the diagonal between the two directions.

31. When, of two motions impressed upon a body, one is the uniform motion which results from an impulse, and the other is produced by a force which acts continually, the path described is a curve. Thus, when we shoot an arrow into the air, the impulse given by the string tends to carry it forward uniformly in a straight line; but gravity draws it continually away from that line, and makes it describe a curve. In the same manner the planets are continually drawn away from the straight lines in which they tend to move, by the attraction of the sun, and are made to describe curved orbits about that body.

32. Third Law. *When bodies act on each other, action and reaction are equal, and in opposite directions.* The meaning of this law is, that when a body imparts a motion in any direction, it loses an equal quantity of its own—that no body loses motion except by imparting an equal amount to other bodies—that when a body receives a blow it gives to the striking body an equal blow—that when one body presses on another it receives from it an equal pressure—that when one body

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31. Under what two forces will a body describe a curve? Examples—An arrow—The planets.

32. Give the third law of motion. Explain its meaning. Exam-

attracts or repels another, it is equally attracted or repelled by the other. If a steamboat should run upon a sloop sailing in the same direction with a slower motion, it might drive it headlong without experiencing any great shock itself; still its own loss of motion would be just equal to that which it imparted to the sloop, but being distributed over a quantity of matter so much greater, the loss might be scarcely perceptible. If a light body, as the wad of a cannon, were fired into the air, it would be stopped by the resistance of the air; but its own motion would be lost only as it imparted the same amount to the air, and thus might be sufficient, on account of the lightness of air, to set a large volume in motion. When the boxer strikes his adversary, he receives an equal blow from the reaction of the part struck; but receiving it on a part of less sensibility, he is less injured by it than his adversary by the blow inflicted on him. One who falls from an eminence on a bed of down, receives in return a resistance equal to the force of the fall, as truly as one who falls on a solid rock; but, on account of the elasticity of the bed, the resistance is received gradually, and is therefore distributed more uniformly over the system. A boatman presses against the shore, the reaction of which sends the boat in the opposite direction. He strikes the water with his oar backward, and the boat moves forward. The fish beats the water with his tail, first on one side and then on the other, and moves forward in the diagonal between the two reactions. The bird beats the air with her wings, and the resistance carries her forward in the opposite direction. All attractions likewise are mutual. The iron attracts the magnet just as much as the magnet attracts the iron. The earth attracts the sun just as much as the sun attracts the earth. In all these cases the mo-

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ples of a steamboat running upon a sloop—a wad fired into the air—a boxer—falling upon a feather bed—a boatman—a bird—attractions.

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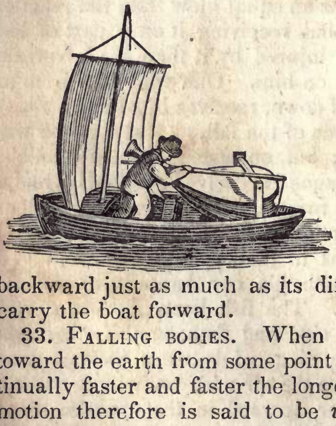
mentum or quantity of motion in the smaller and the larger body, is the same. Thus, when a small boat is drawn by a rope toward a large ship, the ship moves toward the boat as well as the boat toward the ship, and with the same momentum; but the space over which the ship moves is as much less than that of the boat, as its quantity of matter is greater. It makes no difference whether the boat is drawn toward the ship by a man standing in the boat and pulling at a rope fastened to the ship, or by a man standing in the ship and pulling by a rope fastened to the boat. A fisherman once fancied he could manufacture a breeze for himself by mounting a pair of huge bellows in the stern of his boat, and directing the blast upon the sail. But he was surprised to find that it had no effect on the motion of the boat. We see that the reaction of the blast would tend to carry the boat backward just as much as its direct action tended to carry the boat forward.

Fig. 9.



33. Falling bodies. When a body falls freely toward the earth from some point above it, it falls continually faster and faster the longer it is in falling. Its motion therefore is said to be *uniformly accelerated*. All bodies, moreover, light and heavy, would fall equally fast were it not for the resistance of the air, which buoys up the lighter body more than it does the

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Compare the momentum of a small boat with that of a large ship when drawn together. Case of a man who put a pair of bellows to his boat.
33. When is the motion of a body said to be uniformly accelera-

heavier; but in a space free from air, or a vacuum, a feather falls just as fast as a guinea. If a boy knocks a ball with a bat on smooth ice, it will move on uniformly by the impulse it has received; but if several other boys strike it successively the same way, its velocity is continually increased. Now gravity is a force which acts incessantly on falling bodies, and therefore constantly increases their speed. If I ascend a high tower and let a ball fall from my hand to the ground, it will fall $16\frac{1}{12}$ feet in one second, $64\frac{1}{3}$ in two seconds, and $257\frac{1}{3}$ in four seconds; that is, a body will fall four times as far in two seconds as in one, and sixteen times as far in four seconds as in one. Now four is the square of two, and sixteen is the square of four; so that the spaces described by a falling body are proportioned, not simply to the times of falling, but to the *squares* of the times; so that a body falls in ten seconds not merely ten times as far as in one second, but the square of ten, or a hundred times as far.

34. Hence, when bodies fall toward the earth from a great height, they finally acquire prodigious speed. A man falling from a balloon half a mile high, would reach the earth in about half a minute. We seldom see bodies falling from a great height perpendicularly to the earth; but even in rolling down inclined planes, as a rock descending a steep mountain, or a rail car breaking loose from the summit of an inclined plane, we see strikingly exemplified the nature of accelerated motion. A log descending by a long wooden trough down a steep hill, has been known to acquire momentum enough to cut in two a tree of considerable

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ted? How would a guinea and a feather fall in a vacuum? Case of a ball knocked on ice. How much further will a body fall in two seconds than in one? How are the spaces of falling bodies proportioned to the times of falling?

34. In what time would a man fall from a balloon half a mile high? Where do we see the rapid acceleration of falling bodies

size, which it met on leaping from the trough. At a great distance from the earth, the force of gravity becomes sensibly diminished, so that if we could ascend in a balloon four thousand miles above the earth, that is, twice as far from the center of the earth as it is from the center to the surface, the force of attraction would be only one fourth of what it is at the surface of the earth, and a body instead of falling 16 feet in a second would fall only 4 feet. At ten times the distance of the radius of the earth, the force of gravity would be only one hundredth part of what it is at the earth. This fact is expressed by saying, that *the force of gravity is inversely as the square of the distance from the center of the earth*, diminishing in the same proportion as the square of the distance increases. As the moon is about sixty times as far from the center of the earth as the surface of the earth is from the center, if a body were let fall to the earth from such a distance, (the force of gravity being the square of 60, or 3600 times less than it is at the earth,) the body would begin to fall very slowly, moving the first second only the twentieth part of an inch. Were a body to fall toward the earth from the greatest possible distance, the velocity it would acquire would never exceed about 7 miles in a second; and were it thrown upward with a velocity of 7 miles per second, it would never return. This, however, would imply a velocity equal to about twenty times the greatest speed of a cannon-ball.

35. When a body is thrown directly upward, its ascent is *retarded* in the same manner as its descent is accelerated in falling; and it will rise to the height

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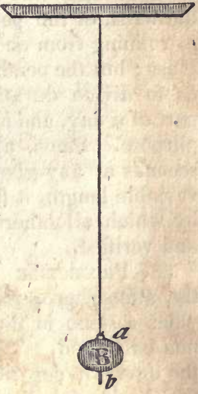
exemplified? Case of a tree leaping from a trough. How is the force of gravity at great distances from the earth? How, 4000 miles off? How, at the distance of the moon? State the law by which gravity decreases. What velocity would a body acquire by falling from the greatest possible distance? How far would it go if thrown upward with a velocity of 7 miles per second?

from which it would have fallen in order to acquire the velocity with which it is thrown upward.

36. VIBRATORY MOTION. Vibratory motion is that which is alternately backward and forward, like the motion of the pendulum of a clock. A pendulum performs its vibrations in equal times, whether they are long or short. Thus, if we suspend two bullets by strings of exactly equal lengths, and make one vibrate over a small arc and the other over a large arc, they will keep pace with each other nearly as well as when their lengths of vibration are equal. Long pendulums vibrate slower than short ones, but not as much slower as the length is greater. A pendulum, to vibrate seconds, must be four times as long as to vibrate half seconds; to vibrate once in ten seconds it must be a hundred times as long as to vibrate in one second, the comparative slowness being proportional to the *square* of the length. The motion of a pendulum is caused by *gravity*. If we draw a pendulum out of its position when at rest, and then let it fall, it will descend again to the lowest point, but will not stop there, for the velocity which it acquires in falling will be sufficient, on account of its inertia, to carry it to the same height on the other side, (Art. 35,) whence it will return again and repeat the same process; and thus, were it not for the resistance of the air, and the

Fig. 10.



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35. When a body is thrown upward, in what manner is it retarded? How high will it rise?

36. Define vibratory motion. How are the times of vibration of a pendulum? Example. How much longer is a pendulum that vibrates seconds, than one that vibrates half seconds? How much

friction at the center of motion, the vibration would continue indefinitely.

37. It is the equality in the vibrations of a pendulum, which is the foundation of its use in *measuring time*. Time may be measured by any thing which divides duration into equal portions, as the pulsations of the wrist, or the period occupied by a portion of sand in running from one vessel to another, as in the hourglass; but the pendulum can be made of such a length as to divide duration into seconds, an exact aliquot part of a day, and is therefore peculiarly useful for this purpose. Since, also, the pendulum which vibrates seconds at any given place, is always of the same invariable length, it forms the best *standard of measures* by which all others used by society can be adjusted and verified.

38. PROJECTILE MOTION. A body projected into the atmosphere, rises and falls in a curve line, as when a stone is thrown, or an arrow shot, or a cannon ball fired. The body itself is called a *projectile*, the curve it describes, the *path* of the projectile, and the horizontal distance between the points of ascent and descent, the *range*. When an arrow is shot, the impulse, if it were the only force concerned, would carry it forward uniformly in a straight line; but the gravity continually bends its course toward the earth and makes it describe a curve. An arrow, (or any missile,) will have the greatest range when shot at an angle of 45° with the horizon; and the range will be the same at any elevation above 45° as at the same number of degrees below 45°. A cannon

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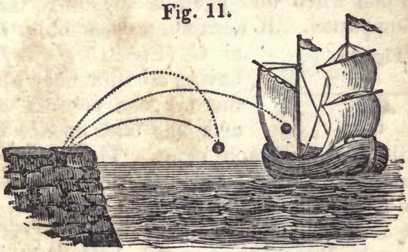
longer to vibrate in 10 seconds than in 1? What causes the motion of a pendulum? Why does it not vibrate forever?

37. On what property of the pendulum is its use for measuring time? What other modes are there? Why is the pendulum better than other modes? On what principle does it become a standard of measures?

38. When is a body called a projectile? What is the curve described called? The horizontal distance? At what angle of eleva-

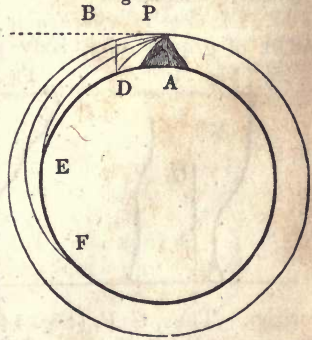
ball shot at an elevation of 60° will fall at the same distance from the gun as when shot at an angle of 30°. Thus, in the annexed diagram, a ship is fired on from a fort, as she is attempting to pass it. The ball fired at an elevation of 45°, is the only one that reaches the ship: the others fall short, and equally when aimed above and below 45°.

Fig. 11.



39. If a cannon ball were fired horizontally from the top of a tower, in the direction of P B, the range would depend on the strength of the charge. With an ordinary charge, it would descend in the curve P D; with a stronger charge, it would move nearer to the horizontal line and descend in PE. We may conceive of the force being sufficient to carry the ball quite clear of the earth, and make it revolve around it in the circle.

Fig. 12.



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tion must an arrow be shot, to have the greatest range? At what two angles would the ranges be equal?

39. Explain Figure 12.

Sec. 3.—*Of the Center of Gravity.*

40. The center of gravity of a body is a certain point about which all parts of the body balance each other, so that when that point is supported, the whole body is supported. If across a perpendicular support, as G, (Fig. 13,) I lay a wire having a ball at each end, B C, there is one point in the wire, and only one, upon which the balls will balance each other. This point is the center of gravity of all the matter contained in the wire and both balls. It is as much nearer the larger, B, as the weight of this exceeds that of C. When two boys balance one another at the ends of a rail, the lighter boy will require his part of the rail to be as much longer as his weight is less. The center of gravity of a regular solid, as a cube, or a sphere, lies in the center of the body, when the structure of the body is uniform throughout; but when one side is heavier than another, the center of gravity lies toward the heavier side.

Fig. 13.

41. *The line of direction* is a line drawn from the center of gravity of a body perpendicularly to the horizon. Thus, G F, (Fig. 14 or 15,) is the line of direction. When the line of direction falls within the

Fig. 14.

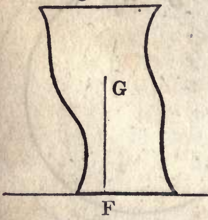
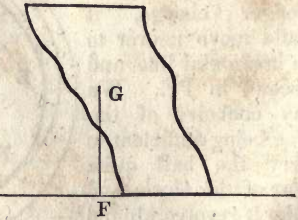


Fig. 15.



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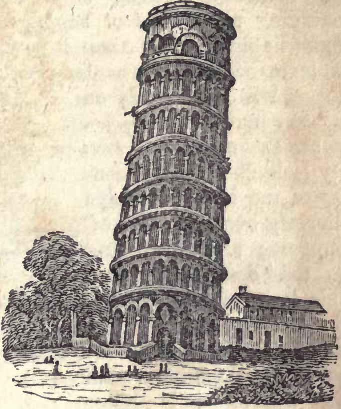
40. Define the center of gravity. Explain Figure 13.

41. Explain Figure 14. Where is the center of gravity of a regular figure situated?

base, (as in Fig. 14,) or part of the body on which it rests, the body will stand; when this line falls without the base, (as in Fig. 15,) the body will fall. At Pisa, in Italy, is a celebrated tower, called the *leaning tower*. It stands firm, although it looks as though it would fall every moment; and being very high, a view from the top is very exciting. Yet there is no danger of its falling, because the line of direction is far within the base. To effect this, the lower part of the tower is made broader than the upper parts, and of heavier materials. These two precautions carry the center of gravity low. Structures in the form of a pyramid, as the Egyptian pyramids, have great firmness, because the line of direction passes so far within the base.

Fig. 16.



42. If we stick a couple of penknives in a small bit of wood, and poise them on the finger, or adjust them so that the center of gravity will fall in the line of a perpendicular pin, the point of the wood will rest firmly on the head of the pin, so that the knives may be made to vibrate on it up and down, or to revolve around it, with-

Fig. 17.

Define the line of direction. Explain Fig. 16, Tower of Pisa. Why are pyramids so firm?

out falling off. A loaded ship is not easily overturned, because the center of gravity is so low, that the line of direction can hardly be made to fall without the base; but a cart loaded with hay or bales of cotton is, on the other hand, easily upset, because the center of gravity is so high. A stage coach carrying passengers or baggage on the top, is much more liable to upset than it is when the load is all on a level with the wheels. A round ball, however large, will rest firmly on a very narrow base, because the center of gravity (which is in the center of the ball) is always directly over the point of support; and, according to the definition, when this is supported, the body is supported. In the annexed diagram, a heavy ball, connected with the figure, bends under the table, and thus brings the center of gravity of the whole within the base, so that the animal rests firmly on his hind legs.

Fig. 18.

43. Animals with four legs walk sooner and more firmly than those with only two, because the line of direction is so much more easily kept within the base. Hence, children creep before they walk, and the art of walking, and even of standing firmly, requires so nice an adjustment of the center of gravity, (which must always be kept over the narrow base

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42. Explain Fig. 18. Why is not a loaded ship easily overturned? A cart loaded with hay—a stage coach—a round ball?

43. Why do four-legged animals walk sooner than two-legged? Why do children creep before they walk?

within the feet,) that it is learned only after much experience. Children at school, also, are sometimes directed to turn out their toes when they walk, and to extend one foot from the other in taking a position to speak, because such attitudes, allowing a broader base for the line of direction, appear more firm and dignified.

44. A boy promised another a cent, if he would pick it up from the floor, standing with his heels close against the wall. But in attempting to pick it up, he pitched upon his face. Performances on the slack rope, which often exhibit astonishing dexterity, depend upon a skilful adjustment of the center of gravity. The process is sometimes aided by holding in the hand a short stick loaded with lead, which is so flourished on one side or the other, as always to keep the center of gravity over the narrow base. Among the ancients, elephants were sometimes trained to walk a tight rope; a feat which was extremely difficult on account of the great weight of the animal.

45. Bodies subject to no other forces than their mutual attraction, and in a situation to approach each other freely, will meet in their common center of gravity. If the earth and moon were left to obey fully their attraction for each other, they would immediately begin to approach each other in a direct line, moving slowly at first, but swifter and swifter, until they would meet in their common center of gravity, which would have its situation as much nearer to the earth as the weight of the earth is greater than that of the moon. So all the planets and the sun, if abandoned to their mutual attraction, would rush together to a common point, which on account of the vast quantity of matter in the sun, lies within that body.

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44. Case of picking up the cent. Performances on the slack rope by men, and even by elephants, explained.

45. Where will bodies meet by their mutual attraction? Examples

Indeed, were all the bodies in the universe abandoned to their mutual attraction, they would meet in their common center of gravity.

SECTION 4.—*Of the Principles of Machinery.*

46. The elements of all machines are found among the *Mechanical Powers*, which are six in number—the Lever, the Wheel and Axle, the Pulley, the Screw, the Inclined Plane, and the Wedge. That which gives motion is called the *power;* that which receives it, the *weight*. The first inquiry is, what power, in the given case, is required just to *balance* the weight. Any increase of power beyond this, would of course put the weight in motion. It is a general principle in Machines, that *the power balances the weight when it has just as much momentum*. Now we may give a small power as much momentum as a great weight, by making it move over as much greater space in the same time, as its quantity of matter is less. One ounce may balance a thousand ounces, if the two be connected together in such a way that the smaller mass, when they are put in motion, moves a thousand times as fast as the larger. If the momentum of the power be increased beyond that of the weight, as may be done by increasing its quantity of matter, then it will overcome the weight and make it move with any required velocity. Whatever structure connects the power and the weight is a machine.

47. THE LEVER. Figure 19 represents a lever of the simplest kind, where P is the *power*, W the *weight*, and

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in the moon and earth, and all the bodies of the solar system—finally, all the bodies in the universe.

46. What are the elements of all Machines? Enumerate the six Mechanical powers. Distinguish between the power and the weight? What is the first inquiry respecting the power? What is a general principle in Machines, respecting *momentum?* How may we give a small power as much momentum as a great weight? How may one ounce balance a thousand? What happens when the momentum of the power is increased beyond that of the weight? What does any structure that connects the power and the weight become?

F the *fulcrum*, or point of support. Now P will just balance W when its weight is as much less as its distance from the fulcrum is greater. For example, if it is three times as far from the fulcrum as W, then one pound will balance three; three pounds will balance nine; and, universally, in an equilibrium, *the power multiplied into its distance from the fulcrum, will equal the weight multiplied into its distance.* In the present case, where the longer arm of the lever is three times the length of the shorter, a power of ten pounds will balance a weight of thirty.

Fig. 19.

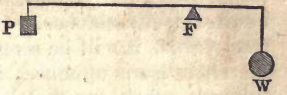
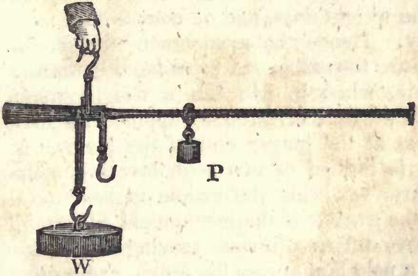


Fig. 20.



48. This principle is exemplified in a common pair of steel-yards. The same power is made to balance different weights of merchandise by attaching W to the shorter and P to the longer arm, and placing P in a notch that is as much farther from the fulcrum

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47. Explain Fig. 19. State the general principle of the equilibrium of the lever. Examples.

48. Explain the principle of Steel-yards. How is the same power made to balance different weights? Explain the difference

as its weight is less than that of the merchandise, W. Steel-yards have commonly a smaller and a larger side; the former being ounce, and the latter quarter-pound notches. On examining such a pair of steel-yards, it will be seen that the hook to which the merchandise is attached, is four times as far from the fulcrum, when we weigh on the small, as when we weigh on the large side. Hence, we have to move the counterpoise over four notches on this side to gain as much power as we gain in one notch on the other. The spaces over which the power and weight move respectively, are in the same proportion. Thus, when the counterpoise is made to balance a weight ten times as large as itself, it will be seen, by making the arm of the steel-yards vibrate up and down, that the counterpoise moves ten times farther, in the same time, than the weight does, and of course with ten times the velocity. Hence the momenta of the power and the weight are the same. A crow-bar illustrates the same principle, when a man lifts a weight much heavier than the amount of force he applies, by making that force act at the longer end of the lever. A pair of shears is formed of two such levers combined; and the nearer we bring the article to be cut to the fulcrum, the greater is the mechanical advantage gained. Two boys differing in size, moving each other at the end of a pole laid across the fence, exemplify the same principle.

49. In the foregoing cases the weight and the power are on opposite sides of the fulcrum, and it is called a lever of the *first* kind. When the power and weight are on the same side of the fulcrum, but the weight nearer to it than the power, it is a lever of the

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between the smaller and the larger side. Show that the momenta of the counterpoise and weight are equal. Examples in a crow-bar—a pair of shears—boys on a rail.

49. Distinguish between levers of the first, second, and third kinds.

Fig. 21.

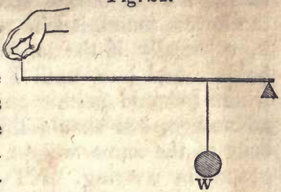
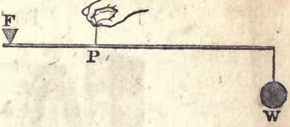


Fig. 22.



second kind, as in the following figure. The mechanical advantage gained here is the same as in the first, for the power moves as much faster than the weight as it is more distant from the fulcrum.—When the power and weight are both on the same side of the fulcrum, but the power nearer to it than the weight, it constitutes a lever of the *third* kind, as in figure 22. A door moving on its hinges is a weight, the matter of which, for our present purpose, may be considered as all collected in the center of gravity, which, on account of the regular figure of the door, is the center of the door; and the effects of any force applied to a body are the same as though all the matter was concentrated in the center of gravity, and the force was applied to that point. Now if, in shutting the door, I place my hand on the edge, this point being farther from the fulcrum than the center of gravity, I gain a mechanical advantage, because the power moves faster than the weight; but if I apply my hand nearer the fulcrum than the center of gravity, then the power moves slower than the weight, and operates under a mechanical disadvantage; and as I approach nearer and nearer to the hinges, the door is shut with greater and greater difficulty. In the former case, the door exemplifies the principle of a lever of the second kind; in the latter, of the third. Suppose a ladder to lie on the ground, and it is required to raise it on one end by

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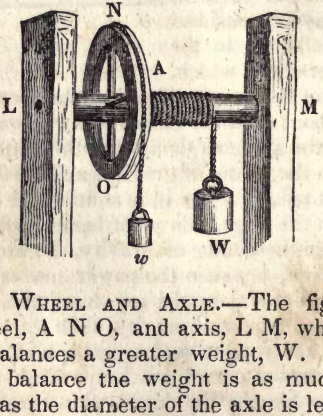
How may a door, in shutting, be either of the second or third kind? Example in a ladder.

taking hold of one of the rounds. If I take hold of the lowest round, it will require a great effort to raise it, especially if the ladder is long. This effort will be less and less, until I come to the middle round, where I should neither gain nor lose any mechanical advantage, but should lift the ladder like any other body of the same weight, if raised directly from the ground by a string. If I apply my hand to any round beyond the middle, toward the farther end, I gain a mechanical advantage, and the greater as I approach nearer to the end of the ladder. We shall leave it to the ingenuity of the pupil to account for these several cases.

Fig. 23.



50. **The Wheel and Axle.**—The figure represents a wheel, A N O, and axis, L M, where a small power *w*, balances a greater weight, W. The power required to balance the weight is as much less than the weight as the diameter of the axle is less than that of the wheel. The wheel and axle has a great analogy to the lever, and is indeed little more than a revolving lever. For if the power were applied to the

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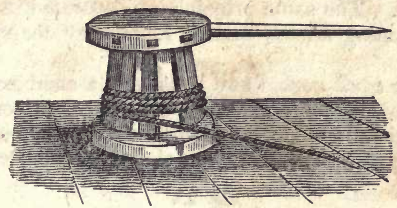
50. Explain Figure 23. How much less is the power than the weight? Show the analogy between the wheel and the lever. Explain Figure 24.

end of one of the spokes of the wheel, that spoke, as it revolved, would describe the figure of a wheel. Thus, the capstan of a ship is a large upright axle, having holes near the top into which long levers are inserted. The men press upon the ends of these and gain a mechanical advantage in proportion as the length of the lever exceeds the radius of the axle. By this means they draw up heavy anchors.

Fig. 24.



51. Wheels are much employed in machinery, and serve very various purposes, although they do not always act upon the principle of the wheel and axle, as just explained. In *carriages*, their chief use is to overcome friction, since a body that rolls on the ground meets with much less resistance than one that slides; and in lifting a wheel over an obstacle, as a stone, a mechanical advantage is gained in the same proportion as the radius of the wheel exceeds that of the axle. Large wheels, therefore, overcome obstacles better than small ones. Wheels are much employed also to *regulate velocity*. Just step into a mechanic's shop and see this use exemplified in the turner's lathe. By passing a band over a large wheel that turns with a steady motion, one may convey that motion to the small

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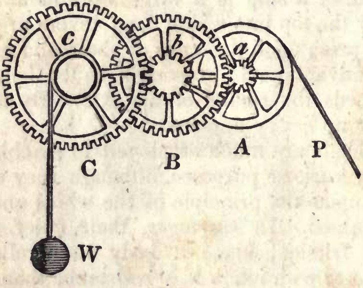
51. What is the use of wheels in carriages? What advantage is gained by rolling instead of sliding? Also, in overcoming obstacles? Which gain most, large or small wheels? Use of wheels in regula-

wheel of a lathe, and the smaller wheel will revolve as much faster than the larger as its diameter is less. Now by using small wheels of different diameters on the lathe, we may increase or diminish the velocity at pleasure. The same principle is illustrated in a common spinning wheel, and in machinery for spinning cotton.

52. In *clock-work*, there is usually a combination of a number of wheels, where one wheel is connected to the axis of another by a small wheel fastened to the axis, called a *pinion*. Thus, the three wheels, A, B, C, are connected. The power is applied to the whee A, on whose axis is the pinion *a*, the teeth of whicl (or *leaves*, as they are called) catch into the teeth of B, whose pinion *b* in like manner turns the wheel C. Here the motion of each succeeding wheel is less than the preceding; for if the pinion *a* have ten leaves, and the wheel B 100 teeth, the pinion in turning once would catch but ten teeth of the wheel, and must therefore turn ten times to turn B once. If the pinion *b* has

Fig. 25.



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ting velocity. How exemplified in a turner's lathe? In a common spinning wheel?

52. Explain the use of wheels in clock-work. Explain Fig. 25.

also 10 leaves, and the wheel C 100 teeth, then C turns ten times as slow as B and a hundred times as slow as A. By altering the proportions between the number of teeth in the wheel and leaves in the pinion, we may alter the velocity of a wheel at pleasure; and this is the way in which wheels are made to move faster or slower, at any required rate, in clocks and watches. If we apply the power at the other end and let the wheel C act on the pinion *b*, and the wheel B on the pinion *a*, then B will turn ten times as fast as C, and A ten times as fast as B, and a hundred times as fast as C; so that, when the wheels carry the pinions, the velocity is increased, but when the pinions carry the wheels, it is diminished.

53. The Pulley.—A pulley is a grooved wheel, around which a rope is passed, and is either fixed or movable. Figure 26 represents a *fixed* pulley; and

Fig. 26.

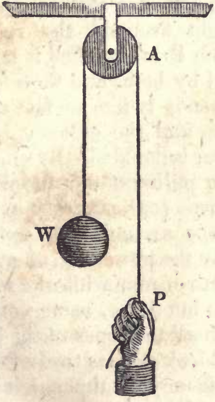
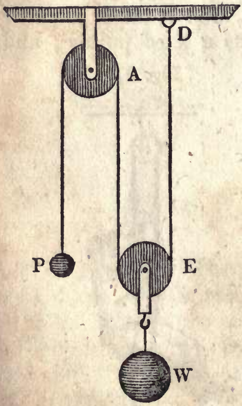


Fig. 27.

Show how the motion is accelerated in one direction and retarded in the other. How may we alter the velocity of a wheel at pleasure? 53. Define the Pulley. Name the *two kinds*. What is the use of here no mechanical advantage is gained, since the power moves just as fast as the weight, and we must remember that it is only when the power moves faster than the weight, that any mechanical advantage is gained. The boy, however, in figure 27, draws himself up by lifting only half his weight, because the two ropes support equal portions of the weight. The principal use of the fixed pulley is to change the direction of the weight. Thus, in drawing a bucket out of a well, it is more convenient to pull downward by a rope passing over a pulley above the head, than upward by drawing directly at the bucket. By the *movable* pulley we gain a mechanical advantage, for by this we can give the weight a slower motion than the power has, and can proportionally increase the efficacy of the power. Thus, in figure 28, as both the ropes, A and E, are shortened as the weight ascends, the rope to which P is attached is lengthened by both, and therefore P descends twice as fast as W rises, and the efficacy of the power is doubled. By employing a pulley with a number of grooves (called a block) with a rope around each, we may make the power run off a great length of rope while the weight rises but little, being equal to the combined length by which all the ropes of the block are shortened. Thus, if the block carries twelve ropes, the power is increased in efficacy 12 times. Instead of a single block with a number of grooves, several

Fig. 28.



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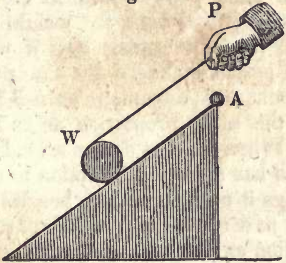
the *fixed* pulley ? Of the *movable* pulley ? Explain the power of a *block* of pulleys.

pulleys with single grooves are combined upon a similar principle. By a block of pulleys, two men will lift a rock out of a quarry a thousand times as heavy as they could lift with their naked hands; but the rope at which they pull will run off a thousand times as fast as the weight rises.

Fig. 29.



54. The Inclined Plane.—The Inclined Plane becomes a mechanical power in consequence of its supporting a part of the weight, and of course leaving only a part to be supported by the power. If a plank, for example, having on it a cannon ball, is laid flat on the ground, it supports the whole weight of the ball. If one end is gradually raised, more and more force must be applied to keep the ball from rolling down the plane: and when the plank becomes perpendicular, a force would be required to sustain the ball equal to its whole weight. We may therefore diminish the effect of gravity, in ascending from one level to another, as much as we please, by making the inclination of the plane small. A builder who was erecting a large edifice, had occasion at last to raise heavy masses of stone to the height of sixty feet. He might have hauled them up by pulleys; but this was inconvenient, and be-

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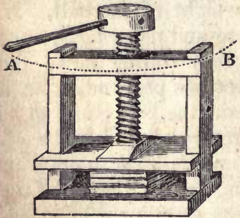
54. How does the Inclined Plane become a *mechanical power?* Ex-

sides, pulleys are subject to so much friction as to occasion a great loss of power. He therefore constructed of timbers and planks, an inclined plane six hundred feet long, and conveyed the blocks of stone up them on rollers. As the plane was ten times as long as it was high, it was as easy to roll 1000 pounds up the plane as it would have been to draw up 100 pounds by a fixed pulley. But as the plane was ten times as long as it was high, the weight would have to pass over ten times the space that it would if it had been raised perpendicularly by the pulley. In all cases, the mechanical advantage gained by the inclined plane is in the same proportion as its length exceeds its height. When a horse draws a loaded cart on level ground, he has merely the friction to overcome; but when he drags it up hill, he has, besides the friction, to lift a certain part of the load, which part will be greater in proportion as the hill is steeper. If the rise is one part in ten, then he would lift one tenth of the load continually.

55. The Screw.—The screw is represented in the following diagram as acting upon a press, which is a very common use that is made of it. As the screw is turned, it advances lengthwise through a space just equal to the distance between the threads. Now if the power be applied directly to the head of the screw, then, in turning the screw once round, the power would move over as much more space than the screw advances, as the circum-

Fig. 30.



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ample. How employed in building? What makes it so hard to draw a load up hill?

55. Explain Fig. 30. How is the mechanical advantage gained,

ference of the head is greater than the distance between the threads. The mechanical advantage gained is in the same proportion; and we may increase the efficacy of the power either by lessening the distance between the threads, or by increasing the space over which the power moves. If we attach a lever to the head of the screw, and apply the hand at the end, then we make the power move over a space vastly greater than that through which the screw advances, and the force becomes very powerful, and will urge down the press upon the books, or any thing in press, with great energy.

56. THE WEDGE.—The Wedge is an instrument used for separating bodies, or the parts of bodies, from each other, as is seen in the common wedge used for splitting rocks or logs of wood. In the kind of wedge in ordinary use, the mechanical advantage gained is greater in proportion as the wedge is thinner. Accordingly, it requires but a small force to drive a thin wedge, but a greater force in proportion as the thickness increases. Cutlery instruments, as knives, axes, and the like, act on the principle of the wedge. When long and proportionally thin, the wedge becomes a mechanical power of great force, sufficient to raise ships from their beds.

57. MACHINES.—Machines are compounded of the mechanical powers variously united. We recognise, at one time, the union of the lever with the screw; at another, of the wheel and axle with the pulley; and, at another, of nearly all the mechanical powers together. The following figure represents a machine for hauling a vessel on the stocks, combining the wheel and axle, the screw, the inclined plane, and the pulley. Each contributes to increase the efficacy of the

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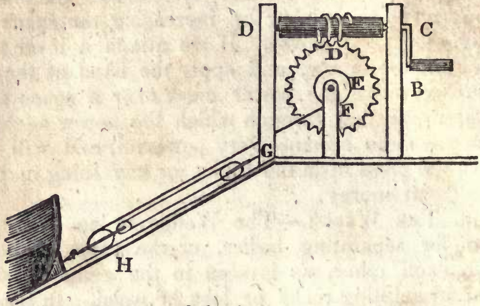
when the power is applied to the *head* of the screw? Also when applied at the end of the *lever*?

56. What is the Wedge *used* for? How is the mechanical advantage of the wedge *increased*?

force, and all together make a powerful machine. A man applies his hand at B, and turns a crank which acts on the principle of the lever upon the screw at D. If the space over which the hand moves in one revolution is a hundred times as great as the distance between the threads of the screw, then the mechanical advantage gained is in the same proportion, and the force with which the screw urges the teeth of the wheel, is a hundred times that applied by the hand to the crank. The diameter of the wheel is four times that of the axle; therefore, the force applied at E is four hundred times that at B. This acts on a combination of pulleys, which, having four ropes, multiply it again four times, and it becomes sixteen hundred. The inclined plane is twice as long as it is high, and therefore doubles the efficacy of the power, and it becomes three thousand and two hundred times what it was originally. So that the single force which a man can exert by means of such a machine is prodigious; and if the machine was so contrived (as it might easily be) that a pair of horses or a yoke of

Fig. 31.



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57. How are *Machines* composed? Explain Fig. 31. How would the *velocity* of the weight compare with that of the power?

cattle, instead of the man, could turn the machine, the force would be adequate to move the largest ship. Such a machine, however, would move the body with extreme slowness. Its motion, in fact, would be diminished as much as the efficacy of the power was increased. This, as we have said before, is a universal principle in mechanics; so that we may find the power exerted by any machine, by seeing how much faster the moving force goes than the weight.

58. Machines, therefore, gain no momentum: the power multiplied into its velocity always equals the weight multiplied into *its* velocity. But although machines do not of themselves generate any force, they enable us to apply it to much greater advantage—to change its direction at pleasure—to regulate its velocity—and to bring in to the aid of the feeble powers of man the energies of the horse and the ox, of water, wind, and steam.

59. FRICTION.—The principles of machinery are first investigated, on the supposition that machines move without resistance from external causes. Then the separate influence of such accidental causes of irregularity, in any given case, is ascertained and applied. The two most general impediments to machines are friction and resistance of the air, which occasion more or less destruction of force in all machines. Friction arises from the resistance which different surfaces meet with in moving on each other. Perfectly smooth surfaces adhere together by a certain force, opposing a corresponding resistance to the motion of the surfaces on one another; but the asperities which exist on most surfaces occasion a much greater resistance. An extreme case is when

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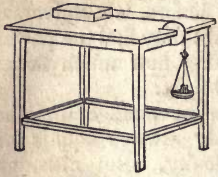
58. Do Machines gain any momentum? What two products are always equal to each other? How do machines aid us?

59. On what *supposition* are the principles of machinery first investigated? What are the two most general *impediments* to machines?

one brush is slid across another, and the hairs interlace. By careful experiments on friction, the following are found to be its principal laws. First, the friction of a body, other things being equal, is proportioned to its *weight*. If a brick is laid on a table, with a string attached to it connected with a scale below, by placing weights in the scale we may ascertain just how much force it takes to drag it off from the table under different circumstances, and this will be the measure of the friction. We should suppose that the friction would be greater on its broad than on its narrow side; but experiments show that it is equal in the two cases, so that *extent of surface* makes no difference when the weight remains the same. We may let the same brick rest on either side, and load it with different weights, equal to its own weight, double, triple, and so on. In all cases, we shall find the friction increased in the same proportion as the weight. Secondly, friction is increased by bodies remaining some time *in contact* with each other; and when the contact is but momentary, as when a body is in very swift motion, the amount of friction is greatly diminished. Thus, when a carriage is in swift motion over a road, it encounters less resistance from friction in passing a given distance, than when it moves slowly. The same is strikingly the case in railway cars.

Fig. 32.



60. *Rolling* are subject to far less friction than *sliding* bodies. Thus, if a coach wheel be *locked*, that is, made to slide down hill instead of rolling, its

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What *causes* friction? State an extreme case. To what is the friction of a body *proportioned?* How is the amount of friction affected by continued *contact?*

60. Difference between *rolling* and *sliding* bodies? Use of *lubrica-*

friction may be so much increased as to check the rapidity of descent in any required degree. Rollers are therefore employed in transporting heavy bodies, to diminish friction; and, for the same purpose, surfaces are made smooth by applying grease, or different pastes, or even water, all of which fill up the inequalities and thus diminish the asperities of the surface. Although friction presents a resistance to machines, yet it has its uses in mechanical operations. It is this which makes the screw and the wedge keep their places; and it is the friction of the surfaces of brick and stone against each other, which gives stability to buildings constructed of them. The wheels of a carriage advance by their friction against the ground. On perfectly smooth ice they would turn without advancing. We could not walk did not friction furnish us with a foothold; and it is for want of friction that walking is so difficult on smooth ice. So rail cars meet with great difficulty in proceeding when the rails have been recently rendered slippery by ice: the wheels turn without advancing. Friction is even employed as a mechanical force, as when a lathe is turned by the friction of a band. Air meets with greater resistance in passing over rough surfaces than water does; for water deposites a film of its own fluid upon the surface over which it moves, and thus lubricates it. Hence water flows in pipes with less resistance than air passes over the surfaces of a rough and sooty chimney.

61. The resistance which bodies meet with in passing through air or water, increases rapidly as the velocity is increased, being proportioned to the *square* of the velocity. Thus, if a steamboat doubles its

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ting substances? Give examples of the *uses* of friction in the screw and the wedge—in the materials of a building—in carriage wheels—in lathes. Which meets with the greater resistance from friction, *water* or *air*?

61. How is friction proportioned to *velocity*? Example.

speed, it encounters not merely twice as much resistance from the water, but four times as much. This makes it much more expensive to move boats rapidly than slowly, for it would require nine times the force to triple the speed.

CHAPTER III.

HYDROSTATICS.

PRESSURE OF FLUIDS—SPECIFIC GRAVITY—MOTION OF FLUIDS—WONDERFUL PROPERTIES COMBINED IN WATER.

62. HYDROSTATICS *is that branch of Natural Philosophy, which treats of the pressure and motion of fluids in the form of water.*

SEC. 1. *Of the* PRESSURE *of Fluids.*

63. Water, on account of the mobility of its parts, may be easily *displaced*, but it is with great difficulty *compressed*. If we take a hollow ball of even so compact a metal as gold, fill it full of water, plug it close, and put it into a vise and compress it, the water will sooner force its way through the gold than yield to the pressure. This is an old experiment, and it led to the belief that water is wholly incompressible; but it is now found that its volume may be reduced to smaller dimensions by subjecting it to very great pressures. Thus, 30,000 pounds pressure to the inch will lessen its bulk one twelfth.

64. *A fluid when at rest, presses equally in all directions.* A point in a tumbler of water, for example, taken at any depth, exerts and sustains the same pressure in all directions, upward, downward, and sidewise. So that if I attach a string to a musket

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62. Define Hydrostatics. 63. Is water *compressible?* Experiment. What force is required to lessen its bulk *one twelfth?*

64. What is the *law* of pressure in all directions? Example.

ball and let it down into water, the weight of the water which rests on its upper side is balanced by an equal pressure on its under side. This is the most remarkable property of fluids, and is what distinguishes them from solids, which press only downward, or in the direction of gravity.

65. *A given pressure, or blow, impressed on any portion of a mass of water confined in a vessel, is distributed equally through all parts of the mass.* If I thrust a cork into a bottle filled with water, so near the top that the cork meets it, the pressure is felt, not merely in the direction of the cork, or just under it, but on all parts of the bottle alike; and the bottle is as likely to break in one part as another, if equally strong throughout, and if not equally strong, it will give way at its weakest point, wherever that is situated. If we insert into a large vessel of water a blown bladder, and then press upon the upper surface of the water with a lid that fits it close, as in figure 33, the bladder will indicate an equal pressure on all sides. A is the lid that fits the jar, water-tight, and is applied to the top of the fluid; B is a small blown bladder, kept in its place by a leaden weight resting on the bottom of the vessel. If a thin glass ball is substituted for the bladder, on pressing down the lid, it will be broken into minute fragments, showing an equal pressure on all sides. The same effects would follow were the pressure applied at the side, or any other part of the vessel, instead of the top.

Fig. 33.

66. This principle operates with astonishing power in the *hydrostatic press*. Figure 34 represents a press

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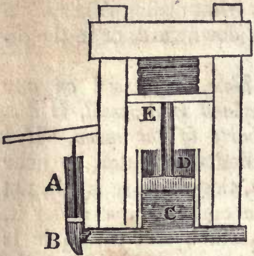
65. How is a pressure on any part of a confined mass of water *distributed?* Example. Explain Figure 33.

Fig. 34.



made of a strong frame of timbers, having a large cylinder, C D, full of water, and opening into a small cylinder, A B, in which a plug (called a *piston*) is moved up and down by the lever attached to it. At D is another piston, which when forced upward presses upon a *follower* at E, which communicates the force to a pile of books supposed in the process of binding. Now if I apply my hand to the lever and force down the piston in AB upon the surface of the water, with whatever force it presses upon the surface of the fluid in the small cylinder, the same is exerted on all parts of the water in the large cylinder, and consequently upon the piston D to push it upward against E. Suppose the number of square inches in the bottom of the piston E, is a thousand times as great as in that of the piston at B; then by urging B forward with a force equal to one hundred pounds, I should communicate to E a pressure of one hundred thousand pounds. The water in the small cylinder would descend a thousand times as much as that in the large cylinder rose, so that the space through which the accumulated force could act would be very small; still it would be sufficient for such articles as books, where the whole compression is but small. Since there is no loss from friction in this machine, a man can by means of it exert a greater power than by any other to which he can apply his own strength. He can by means of it crush rocks,

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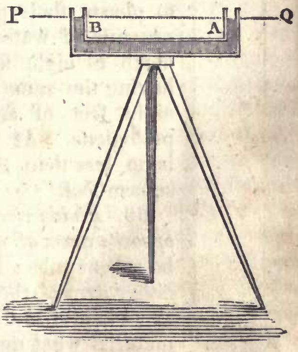
66. Describe the *Hydrostatic Press.* Suppose the number of square inches in the larger piston is a thousand times as great as in the smaller? Uses of the Hydrostatic Press?

and cut in two the largest bars of iron. The hydrostatic press is much used as an oil press, as in extracting oil from flaxseed; and also for packing hay, cotton, and other light substances.

67. *The surface of a fluid at rest is horizontal.* This property is applied to the construction of the FLUID LEVEL, used by carpenters, masons, and othe workmen. It usually consists of a flat rule, having a horizontal glass tube on the upper side, containing alcohol, (which is preferred to water because it never freezes.) The tube is not quite full of the fluid, so that when laid on its side a bubble of air floats on the upper surface. When this is exactly at a given mark near the middle, then the surface on which the rule is laid is level. Figure 36 represents a levelling staff much used in surveying and grading lands. The liquid in the two arms of the tube at A and B being precisely on a level, any two remote objects, P and Q, may be brought accurately to the same level by *sighting* P with the eye at A; that is, bringing it into the same horizontal line with the surfaces of A and B, and then sighting Q in the same manner.

Fig. 35.

Fig. 36.



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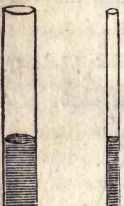
67. How is the *surface* of a fluid when at rest? Describe the *fluid-level* and the *levelling staff*.

68. *The pressure upon any portion of a column of fluid, is proportioned to its depth below the surface.* If we let down a junk bottle into the sea, the pressure on all sides of it would continually increase as it descended, until it would be sufficient to crush it. Its great strength, however, would enable it to bear a prodigious pressure. When an empty bottle, corked closely, is let down to a great depth, on drawing it up, it is found full of salt water, and yet the cork undisturbed. At a certain depth, the pressure on the cork is such as to contract its dimensions, and yet, being equally pressed on all sides, it is not displaced. Its size being contracted, the water runs in at the sides; but on rising to the surface, the cork swells again to its former bulk. When the stopper does not admit of compression, the water sometimes is forced through its pores, and thus fills the bottle. Ships sunk at a great depth, have their wood rendered so heavy by the great quantity of water forced into it, that when they go to pieces their parts do not rise. The pressure of water on a square foot, at the depth of eight feet, is 500 pounds; and having the same amount added for every eight feet of descent, it soon becomes prodigious. At the depth of a mile, it is no less than 330,000 pounds upon the square foot.

Fig. 37.



69. *Fluids rise to the same level in the opposite arms of a bent tube.* Let Fig. 37 be a bent tube: if water be poured into either arm of the tube, it will rise to the same height in the other arm. Nor is it material what may be the shape, size, or

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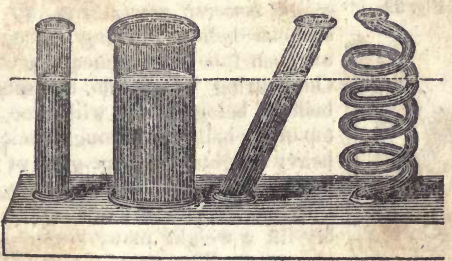
68. How is the pressure of a column of fluid at different *depths?* Example in a *junk-bottle.* What happens to a corked bottle sunk to a great depth? What is the pressure on a square foot at the depth of *eight* feet—and a *mile?*

inclination of the opposite arms. Figure 38 represents a variety of vessels and tubes open at top, but communicating with a common cistern of water below. If we pour water into any one of these, so as to fill it to any height, the water will be at the same height in each of the others. Hence, water conveyed in aqueducts, or running in natural confined channels, will rise just as high as its source, and no higher. Between the place of exit and the spring, the ground may rise into hills and descend into valleys, and the pipes which convey the water may follow all the irregularities of the country, and still the water will run freely, provided no pipe is laid higher than the level of the spring.

Fig. 38.



70. *The pressure of a column of water upon the bottom of a vessel, depends wholly upon the height of the column, without regard to its shape or size.* In Fig. 38 the pressure on the bottom of the cistern will be the same, whether one tube is attached, or the whole number, or the vessel itself is raised to the same height all the way of the same size as at the bottom,

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69. Fluids in the opposite arms of a *bent tube?* What does Fig. 38 represent? How high will water in an *aqueduct* rise?

70. Upon what does the pressure of a column of fluid on the *bottom*

or even if swelled out like a funnel, so as to be much larger above than below. On this principle is founded the hydrostatic paradox—that *any quantity of water however small may be made to raise any weight however great.* Fig. 39 represents a bellows having on one side an open tube communicating with it. On pouring water into the tube (the bellows being full) it will force up the top of the bellows, although loaded with heavy weights. A wine-glass of water, for example, will raise the boys that stand on the bellows, and would sensibly lift a weight many hundred times as great. The principle is the same as in the hydrostatic press. Here the weight of the column of water affords the power that acts on the larger end of the bellows, as in the press the force of the piston in the small cylinder acts on that in the larger.

Fig. 39.

Sec. 2. *Of Specific Gravity.*

71. Specific Gravity *is the weight of a body compared with another of the same bulk, taken as a standard.* Water is the standard for solids and liquids; common air for gases. The specific gravity of a mineral, for example, or of alcohol, is its weight compared with that of a mass of water of exactly the same volume; the specific gravity of steam is its weight compared with that of the same volume of atmospheric air. We must know, then, what an equal volume of the standard would weigh. This is ascer-

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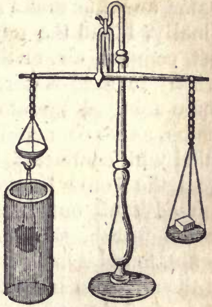
of a vessel depend? State the principle called the *hydrostatic paradox*. Explain Fig. 39.

71. Define *specific gravity*. What is the standard for *solids*—what for *liquids*—what for *gases?* What must we *know* in order to find the

tained in the case of a solid, by finding how much less the body weighs in water than in air; and, in the case of a liquid or a gas, by weighing equal volumes of the body and of air. Wishing to know how much heavier a certain ore, which I suspected to be silver, was than water, I tried to compare its weight with that of an equal bulk of water; but the ore being of very irregular shape, I found great difficulty in measuring it accurately to find the number of solid inches in it, so that I could weigh it against the same number of inches of water. But learning that a body when weighed in water weighs as much less than when weighed in air, as is just equal to the weight of the same volume of water, I attached a string to the ore, hung it to one arm of the balance, and found its weight to be 4.75 ounces; and then bringing a tumbler of water under the suspended ore so as to immerse it, I found it did not in this situation weigh as much as before, but I had to take out 1.25 ounces to restore the balance. This, then, was what the ore lost in water, and was the weight of an equal volume of water. Now I have found that the ore weighs four ounces and three quarters, while the same bulk of water weighs only one ounce and a quarter. I see, therefore, at once, that the ore is about four times as heavy as water; but to find the exact specific gravity, I see how many times the weight of the ore is greater than that of an equal volume of water, by dividing 4.75 by 1.25, which gives 3.8 as

Fig 40.



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specific gravity of a body? Describe the way of finding the specific gravity of an *ore*—also of *alcohol*—also of *carbonic acid.*

the exact specific gravity of the ore. I conclude, therefore, that it cannot contain much silver, if any; otherwise it would be heavier. Again, desiring to find the specific gravity of some alcohol, (which is better in proportion as it is lighter,) I took a small vial, counterpoised it in a pair of delicate scales, and poured in water gradually till I had introduced exactly 1000 grains. I then set the vial on the table, and placing my eye accurately on a level with the surface of the water, I made a fine mark with a small file just round the water line. On emptying out the water and filling the vial to the same mark with the alcohol, I found the weight of it to be 815 grains. I therefore inferred that its specific gravity was 815, water being 1000. Having now my vial ready, I filled it to the mark successively with half a dozen different liquors, some lighter and some heavier than water, and thus found the exact specific gravity of each. Finally, I had the curiosity to see which is the heaviest, common air, or that sort of air which sparkles so briskly in soda-water, and in bottled beer, called carbonic acid. I therefore weighed a light glass bottle, which, as we commonly say, was empty, but was really filled with common air, and then withdrawing the air from the bottle by means of a kind of syringe which sucked it all out, I then turned the stop-cock attached to the mouth, shut the bottle close, and weighing it again, found it had lost 40 grains, which was the weight of the air. At last I filled the bottle with carbonic acid instead of air, and weighing again, found the vessel now weighed 60 grains more than before. This was the weight of the carbonic acid; and now having found that when we take equal bulks of common air and carbonic acid, the latter weighs 60 grains, while the former weighs only 40, I infer that the carbonic acid is one half heavier than common air; that is, its specific gravity is 1.5. By a similar process, I found that hydrogen gas, one of the elements of water, is more than thirteen times as light as air, being the lightest of all known bodies.

72. A body *floats in water at any depth*, when its specific gravity is just equal to that of water. The human system is a little heavier than water, and therefore tends to sink in it; but if we strike the water downward, its reaction will keep us up, acting as it does in a direction opposite to that of gravity. A very slight blow upon the water is sufficient to balance the downward tendency, and therefore *swimming* becomes an easy matter when skillfully practised. As we lose in water as much of our weight as the same bulk of water would weigh, and that is nearly the whole, it is only the slight excess of our weight which we have to sustain in swimming. Indeed, if we could keep our lungs constantly inflated, we should require no reaction to keep us up, but should float on the surface. Dr. Franklin when a boy swam across a river by the aid of his kite, which supplied the upward force necessary to sustain him, instead of the reaction of the water. Fishes are nearly of the same specific gravity as the water in which they live. They are supplied with a small air-bladder, which they have the power of compressing and dilating. When they wish to sink they compress this bladder, and their specific gravity is then greater than that of the water; and they easily rise again by suffering the bladder to dilate. Birds float in the atmosphere on similar principles. Being but little heavier, bulk for bulk, than the air, very slight blows with their wings create the reaction in an upward direction, which is necessary to sustain them; stronger blows cause the reaction to overbalance

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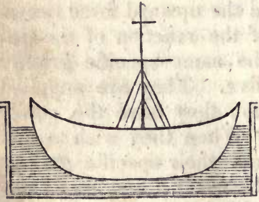
72. When does a body *float* in water? How is the body supported in *swimming?* How did *Dr. Franklin* swim across a river? How do *fishes* ascend and descend? How do *birds* fly?

the excess of their specific gravity over that of the air, and they rise with the difference.

73. When a body *floats on the surface of water,* it displaces as much weight of water as is equal to its own weight. Thus, if I place a wooden block weighing four ounces in a tumbler of water even full, just four ounces of the water will run over, as we may ascertain by collecting and weighing it. Upon this principle ships float on water. In proportion as we lade the ship, it sinks deeper and deeper, the weight of water displaced always being exactly equal to the weight of the ship and cargo. The actual weight of the ship and cargo may be easily ascertained on this principle; for if we float the ship into a dock of known size, containing a given quantity of water, the weight of the ship and cargo may be determined from the rise of the water in the dock. A boy wished to find the tonnage of his boat. He therefore loaded it as heavy as it would swim, and then transferred it to a small box which he had made, and of which he knew the exact dimensions. He then poured into the box a pound of water at a time, and when it had settled to a good level, he made a mark at the water line, and adding one pound of water at a time, he thus had marks at different heights, from one pound up to twenty. He found that four pounds of water were amply sufficient to float his boat, and when the boat was laid upon it, the water rose on the sides to the nineteenth mark. Consequently the boat had raised the water fifteen

Fig. 41.



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73. How much water does a floating body *displace?* Example Method of finding the tonnage of a *ship?* How did the *boy* find the tonnage of his boat?

marks, and its weight was of course fifteen pounds; for it weighed just as much as the water would have weighed which it would have taken to raise the level from the fourth to the nineteenth mark.

Sec. 3. *Of the* Motion *of Fluids.*

74. That part of hydrostatics which treats of the mechanical properties and agencies of running water, is called *Hydraulics*, and machines carried by water, or used for raising it, *Hydraulic machines.* It embraces what relates to water flowing in open channels, as rivers and canals; or in pipes, as aqueducts; or issuing from reservoirs in jets and fountains; or falling, as in dams and cascades; or oscillating in waves. A river or canal is water rolling down hill, and would be subject to the same law as other bodies descending inclined planes, were it not for the numerous impediments which oppose the full operation of the law. Now a body rolling down an inclined plane has its motion constantly accelerated, like a body falling perpendicularly, gaining the same speed in descending the plane that it would in falling through the perpendicular height of the plane. Hence when a body rolls down a long plane without obstruction, it soon acquires an immense velocity, as is seen in a rock rolling down a long hill. In the same manner, a body of water descending in a river constantly tends to run faster and faster, and would soon acquire a most destructive momentum, were it not retarded by numerous counteracting causes, the chief of which are the friction of the banks and bottom, and the resistance occasioned by its winding course, every turn opposing an impediment of more or less force. By such a circuitous route two benefits are gained—the rapidity of the

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74. Define *Hydraulics.* What subjects does it *embrace?* Are *rivers* subject to the laws of falling bodies? What benefits arise from

stream is checked, and its advantages are more widely distributed. A river flows faster in the channel, towards the middle, than near the banks, because it is less retarded by friction; and during a freshet the rapidity is greatly increased, because since the waters that are piled on the original bed are subject to little friction, they exhibit something of the accelerated motion of bodies rolling freely down inclined planes. A very slight fall is sufficient to give motion to water where the impediments are slight. The Croton Aqueduct, that waters the city of New York, falls but one foot in a mile. Three feet fall per mile makes a mountain torrent. Some rivers do not fall more than 500 feet in 1000 miles, or a foot in two miles, and require a number of days, or even weeks, to pass over this distance.

75. The Aqueducts which the ancient Romans and Carthaginians built for watering their cities, were among the greatest of their works, some of which have remained until the present day. Large streams were conducted for many miles, sometimes not less than a hundred, in open canals, carried through mountains and led over deep valleys, on stupendous arches of masonry. Some have supposed that the ancients must have been unacquainted with the principle, that water flowing in pipes will rise as high as its source, since, had they known this, they might have conveyed water in pipes instead of such expensive structures; these might have ascended and descended, following all the inequalities of the face of the country, provided they were in no part higher than the head or spring. It is found, however, that they were acquainted with the principle, but prefer-

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the *circuitous* routes of rivers? What part of a river flows *fastest?* Why do rivers run so swift during a *freshet?* What *fall* per mile have the Croton Water Works?

75. What of the Aqueducts of the Romans and Carthaginians?

red to construct their aqueducts of open channels rather than pipes. Suitable pipes, at that age, would have been very costly. They are apt also to become clogged; and although they might have followed the inequalities of hills and valleys, yet when they descended and ascended far from the general level, they would be obliged to encounter an enormous pressure, since in a column of water, the pressure on any part is proportioned to the depth below the surface of the water, increasing five hundred pounds to the square foot for every eight feet of descent. A pipe, therefore, fifty feet deep and full of water, would have to bear a pressure at the lower part of more than three thousand pounds to the square foot, and must be made proportionally strong, and would be apt to leak at the joints. Even at the present day, it is found more eligible to water cities by open aqueducts than by pipes, as is done in the new Croton Water Works for watering the city of New York. Here an artificial river of the purest water is conveyed from the county of Westchester, forty-one miles above the city, to a vast reservoir capable of holding 150,000,000 of gallons, where it has opportunity to deposit any sediment or impurities it may have taken up on its way, and to absorb air, which gives it life and briskness. From the reservoir it is distributed to all parts of the city in pipes, affording an ample supply for domestic uses, for watering and washing the streets, and for extinguishing fires.

76. When a plug is removed from the top of one of the pipes of an aqueduct, the water spouts upward in a jet; for, since water thus situated tends to rise as high as its source, it will spout to that height when unconfined. At least it would ascend to that height

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Were the ancients acquainted with the principle that water ascends to the level of its source? Describe the Croton Water Works.

76. Why does water *spout* from a pipe of an aqueduct? How *high* will it spout?

were it not for the resistance of the air, which prevents its attaining that full height. It is on this principle that *fountains* are constructed. If we open a vent in the side of a water-pipe, so as to let the jet out obliquely, it will form the curve of a parabola; and by letting out the jet through different orifices, the curves may be varied, and beautiful and pleasing figures exhibited, as is shown at the Park Fountain in the city of New York.

77. In building tall or deep cisterns, we must remember, that the pressure on any part of the cistern increases with the depth, and hence that the lower parts require to be made stronger and closer than the upper, else they will either burst in pieces or leak. A philosopher wishing to provide a constant supply of water near his house, constructed a large cistern six feet high, and contrived to convey a small stream of water to the top which kept it always full and running over by a waste-pipe. In the side of the cistern he inserted two large stop-cocks of equal size, the first, one foot, and the other four feet from the top, supposing that he might, in a given time, draw off either one gallon or four gallons; but he was surprised to find that he could obtain from the lower stop-cock only *twice* as much as from the upper. How, thought he, is this consistent with the principle that the pressure is proportioned to the depth? If it presses against the side of the cistern at the lower level four times as much as at the upper, why do not four times as many gallons run out when the stopper is opened? On reflection, however, he perceived that the pressure on the side must be proportioned to the *momentum*, which depends on two things—the quantity of matter and the velocity; and of course that twice the quantity of

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77. How must we provide for the *strength* of a pipe at different heights? Relate the story of the philosopher drawing water from a cistern. To what is the quantity of water discharged from a cistern at

water flowing with twice the velocity, would have just four times the momentum. Hence he learned the grand principle, that in a column of water kept constantly full, the quantity discharged from any orifice in the side, is proportioned to the *square root* of the depth below the surface of the fluid. So that, to draw off twice as much, we must make the opening four times as deep, and to draw off three times as much, we must make it nine times as deep.

78. The philosopher tried another experiment with his cistern. He turned off the run of water that supplied the cistern, and then opened the upper stopcock, and found it took just five minutes to draw off the water to that depth. He then let in the run that supplied the cistern and kept it constantly full. Now opening the same orifice again, and drawing off for five minutes more, he found that he caught just twice as much water as before. From this he inferred, that if a vessel discharges a certain quantity of water in emptying itself to a certain level, it will discharge twice as much in the same time, when the vessel is kept constantly full.

79. Water issues from the bottom or side of a vessel with the same force that it would acquire by falling through the perpendicular height of the column. It would therefore seem to make no difference whether we let water fall upon a water-wheel from the top of a cistern, or whether we raise a gate at the bottom of the column, and let the water issue so as to strike the wheel there, since it would strike the wheel in both cases with the same velocity, except what might be lost in the falling column by the resistance

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different depths *proportioned?* How much lower must we go to double the quantity?

78. What *other* experiment did he try? How much more is discharged when the vessel is kept constantly full?

79. With what *force* does water issue from the bottom or side of a vessel? Does it make any difference whether water falls upon a

of the air. A waterfall like that of Niagara, where an immense body of water rolls first in *rapids* down a long inclined plane, and then descends perpendicularly from a great height, affords one of the greatest exhibitions of mechanical power ever seen. The Falls of Niagara contain power enough to turn all the mills and machinery in the world. They waste a greater amount of power every minute, than was expended in building the pyramids of Egypt; for, in that short space of time, millions of pounds of water go over the falls, and each pound, by the velocity it gains in falling first down the rapids, and then perpendicularly, acquires resistless energy. Water falling one hundred feet would strike on every square foot with a force of more than six thousand pounds.

80. Man imitates the power of the natural waterfall when he builds a dam across a stream, raising it above its natural level, and then turning aside more or less of it into a narrow channel, makes it acquire momentum while regaining its original level. When it has gained the requisite force, he turns it upon a water-wheel usually of great size, from which, by means of machinery, the force is distributed wherever it is wanted, and so applied as to do all sorts of work. When a run of water first strikes a wheel at rest, it strikes it with its full force; but as the wheel moves before it, the effect of the force is diminished, and if the wheel acquired the same velocity as the stream, the force would become nothing. The wheel is retarded by making it do more and more work, or carry a greater weight, until it acquires a uniform motion at a certain rate, which ought to be that at which the force of the stream produces the greatest effect. This is

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wheel from the *top*, or issues upon it from the *bottom*? What of the Falls of Niagara?

80. When does man *imitate* the waterfall? With what force does a run of water *first* strike a wheel? How when the wheel is in motion?

in some cases when the wheel moves half as fast as the stream. That a current of water or of wind strikes an object with less force when the object is moving the same way, is a general principle. Thus, when a steamboat is moving directly before the wind, she would derive little aid from sails unless the wind were high, for she would "run away from the breeze;" that is, the wind would produce no effect any farther than its velocity exceeded that of the boat, and if it were just equal to that, the effect would be absolutely nothing. A man in a balloon, carried forward by a wind blowing a hundred miles an hour, would speedily acquire the same velocity with the wind, and therefore appear to himself to be all the while in a calm. Although the earth is constantly revolving round the sun with inconceivable rapidity, yet as we have the same velocity we seem to be at rest.

SEC. 4. *Of the Remarkable Properties combined in Water.*

81. Water combines in itself a variety of useful properties, all designed for the benefit of man. First, *Natural History* leads us to contemplate it in its various aspects. It covers about three fourths of the globe, and is distributed into oceans, seas, and lakes, rivers, springs, and atmospheric vapor. By the agency of heat, water is constantly rising in vapor on all parts of the ocean. This mingles with the air in an invisible elastic state, being separated in the process of evaporation from its salt and every other impurity. More or less of it is conveyed over the land by winds, and falls upon it in dew, and rain, and snow. A part of this filters through the sand, runs down in the

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In what case does the stream produce its greatest effect? Example in a steamboat. How would a man in a balloon appear to himself to be situated when moving with the *same velocity* as the wind?

81. What *part* of the earth is covered with water? In what different *forms?* What benefits flow from *rivers?* Also from the *ocean?*

crevices of rocks, and collects in pure fountains not far below the surface, where it may be easily reached in almost every place, by digging wells. In various places it flows out by its own pressure, in springs and streamlets, which unite in rivulets, and these in rivers, which return the water to the sea. But rivers as they run are made to impart fertility, and to furnish an avenue by which vessels and steamboats may penetrate into the heart of every country, and convey to the remotest cities the riches of every clime. As rivers furnish an entrance into the interior of countries, so the ocean forms the great highway between nations, and unites all nations in the bands of commerce. Still further, to serve the grand cause of benevolence, the ocean is filled with living beings innumerable, which are not, like land animals, confined to the surface, but occupy the depth of at least six hundred feet, and thus enjoy a far more extensive domain than the part of the animal creation that inherits the land.

82. Secondly, *Chemistry* regards water with no less interest than Natural History. Its very *composition* is admirable, being constituted of two substances, oxygen and hydrogen, which, when united with heat, are separated in the gaseous form, and each possesses the most curious and wonderful properties. Oxygen is found as an element in nearly all bodies in nature; it is the part of atmospheric air which sustains all animal life and supports all fires; and it is the most active agent in producing all the changes of matter which take place both in nature and art. Hydrogen gas is the most combustible of all bodies, and is in fact what we see burning in nearly every sort of flame. As a *solvent*, water performs the most useful service to man, removing every impurity from his clothing or his person, dissolving and prepar-

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82. What is the *composition* of water? What of *oxygen* and *hydrogen?* What of water as a *solvent?* Of the different *states* of water?

ing his food, and entering largely into nearly all the processes of the arts. By the different *states* which water assumes, of ice and snow and vapor, it performs important offices in the economy of Nature, as well as in its native state of a liquid. These changes of state regulate the temperature of the atmosphere, and preserve it from dangerous excesses both of heat and cold. On the one hand, on the approach of winter in cold climates, water changes to ice and gives out a vast amount of heat that kept it in the liquid state; and on the approach of summer, to check the too rapid increase of temperature, the same heat which was given out when water was changed into ice, is now absorbed and withdrawn from the atmosphere, as ice is changed back to water. Moreover, during the heat of summer, the evaporation of water, a very cooling process, checks the tendency to excess of the heat of the sun, and guards us from all danger on that hand. Ice, by covering the rivers, keeps them from freezing except on the surface; and snow is a warm and downy covering thrown over the earth to protect the vegetable kingdom by confining the heat of the earth.

83. Thirdly, it is the province of *Physiology* to contemplate the relations of water to the vegetable and animal kingdoms. Water is the chief food of plants, which it nourishes, either by supplying a part of their elements, or by dissolving their nutriment, and thus preparing it for circulation; and hence water is indispensable to the life and growth of all vegetables. To animals and man, it furnishes the best and only necessary beverage; it is the medium by which our food is prepared; and it acts medicinally in various ways, both internally and externally.

How does it check the *cold* of winter and the ***heat*** of summer? Useful properties of *ice* and *snow?*

83. What are the relations of water to the *vegetable* kingdom? What to *animals* and *man?*

84. Finally, the *Mechanical* relations of water, such as those we have been considering in the preceding pages, are hardly less remarkable and important than the rest. By its *mobility*, it maintains its own level and keeps itself within its prescribed bounds; by its *buoyancy*, it furnishes a habitation for numerous tribes of fishes, and lays the foundation of the whole art of navigation; by its *pressure* in all directions, it gives the first indication of containing great mechanical energy, which is more fully developed in the immense force of running water, which may be regarded as a repository of power kept in readiness for the use of man; and, finally, by its property of being converted into *steam*, it discloses a new and inexhaustible fountain of mechanical force, which man may employ in any degree of intensity to perform the humblest and the mightiest of his works.

CHAPTER IV.

PNEUMATICS.

PROPERTIES OF ELASTIC FLUIDS—AIR-PUMP—COMMON PUMP—SYPHON—BAROMETER—CONDENSER—FIRE ENGINE—STEAM AND ITS PROPERTIES—STEAM ENGINE.

85. Pneumatics *is that branch of Natural Philosophy which treats of the pressure and motion of elastic fluids.* Elastic fluids are those which are capable of contracting or dilating their volume under different degrees of pressure. They are of two kinds, *gases* and *vapors.* Gases constantly retain the elastic invisible state; vapors remain in this state only when heated to a certain degree, but return to the liquid

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84. Advantages of its *mobility*—of its *pressure*—of its capacity of being converted into *steam*.

85. Define Pneumatics. What are elastic fluids? State the two kinds and distinguish between them. What two elastic fluids are

state when cooled. Common air is a gas, steam a vapor. Although there are many different gases and vapors known to Chemistry, yet air and steam are the elastic fluids chiefly regarded in Natural Philosophy. Air and steam are both commonly invisible; but air, when we look through an extensive body of it, appears of a delicate blue or azure color, which habit leads us to refer to distant objects seen through it. It is not the distant mountain that is blue, but the air through which we see it. Air also sometimes becomes visible when ascending and descending currents mix, as over a pan of coals, or a hot chimney, when we see a wavy appearance, which is air itself. Vapors also exhibit naturally some variety of colors, as yellow and purple; but the vapor of water or steam is usually invisible. We must carefully distinguish between elastic vapor and the *mist* which issues from a tea-kettle. This is vapor *condensed*, or restored to the state of water, and it is only at the mouth of the tea-kettle, where it is hot, that it is in the state of steam, and there it is invisible.

86. The general principles of mechanics apply to liquids and gases, as well as to solids, all bodies being subject alike to the laws of motion; but the property of *mobility of parts*, which characterizes liquids, and of *elasticity* which characterizes gases and vapors, gives them severally additional properties, which lay the foundation of hydrostatics and pneumatics. Although we do not usually *see* gases and vapors, yet we find in them properties of matter enough to prove their materiality. In common with solids, they have impenetrability, inertia, and weight; in common with liquids, they are subject to the law of equal pressure in all directions, and when confined they transmit the

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chiefly regarded in Natural Philosophy? When is air visible? Are vapors ever visible?

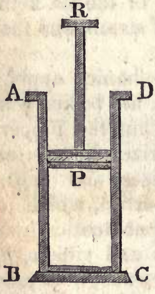
86. Do the general principles of Mechanics apply to liquids and

effects of a pressure or blow upon any one part of the vessel, to all parts alike ; but in their elasticity, they differ from both solids and liquids. Since air and steam are the elastic fluids with which Natural Philosophy is chiefly concerned, we shall consider each of these separately.

Sec. 1. *Of Atmospheric Air.*

87. We may readily verify upon atmospheric air, the various properties of an elastic fluid. Its impenetrability, or the property of excluding all other matter from the space it occupies, will be manifested if we invert a tall tumbler in water. It will permit the water to occupy more and more of the space as we depress it farther, but will never cease to exclude the water from a certain portion of the tumbler which it occupies. We may render this experiment more striking, by employing a glass cylinder and piston, as is represented in Fig. 42. Let A B C D represent a hollow cylinder, made perfectly smooth and regular on the inside, and P a short solid cylinder, called a *piston*, moving up and down in it air-tight, and R the piston-rod. Now when we insert the piston near the top of the cylinder, the space below it is filled with air. On depressing the piston, the air, on account of its elasticity, gives way, and we at first feel but little resistance; but as we thrust it down nearer to the bottom, the resistance increases, and finally be-

Fig. 42.



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gases ? What property characterizes liquids, and what solids ? What properties of matter have gases and vapors ?

87. Show how air is proved to be material. Explain Figure 42. State the different principles which this apparatus is capable of

comes so great that we cannot depress it any farther by the strength of the hand. If we apply heavy weights, we may force it nearer and nearer to the bottom of the cylinder; but no power will bring it into contact with the bottom. This experiment may be so varied as to prove several things. First, it shows that air is impenetrable; secondly, that it may be indefinitely compressed—all the air of a large room might be reduced to a thimble-full, and on removing the pressure, it would immediately recover its original volume; thirdly, that the resistance increases the more it is compressed. We will graduate the cylinder into a thousand equal divisions, by horizontal marks numbered from the bottom upward from one to one thousand, and place on the pan at the top of the piston-rod a few grains, so as just to overcome the friction of the piston against the sides of the cylinder. We will now put on weights successively, until we have sunk the piston half way, when the air occupies five hundred instead of a thousand parts of the cylinder. If we double the weight, it will not carry the piston the same distance as before, that is to the bottom, but only through half the remaining space, so that the air now occupies one fourth of the capacity of the cylinder. If we double the present weight, it will again be compressed one half, so as to fill but an eighth part of the cylinder. We find, therefore, that a double force of compression, always reduces to half the former volume. This law is expressed by saying, that *the volume of a given weight of air is inversely as the compressing force.*

88. Air has the property of *inertia*. It remains at

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proving. How is the volume of a given weight of air proportioned to the compressing force?

88. Why has air the property of inertia? State the experiment which shows that air has weight. Why is air called a fluid? Have the particles of elastic fluids any cohesion?

rest unless put in motion by some force, and continues to move until some adequate force stops it. When put in motion by any moving body, it destroys just as much motion in that body as it receives from it; and it loses its motion only as it imparts the same amount to some other matter. A large body moving swiftly through the air meets with great resistance; but whatever motion it loses, it imparts to the air, which might be sufficient to produce a high wind. Air also has *weight*. If we balance a light bottle, containing a hundred cubic inches, in a delicate pair of scales, having just pumped out all the air from the bottle, and then open the stopper, and admit the air again, we find the vessel has gained in weight 30½ grains. We call air and all other gases and vapors *fluids*, because their particles move so easily among themselves. The particles of elastic fluids have no cohesion, but on the other hand, have a mutual repulsion, which causes them to fly off from each other as soon as the compressing force is removed or diminished.

89. The lower portions of air which lie next to the earth, are pressed by the whole weight of the atmosphere, which is found to amount to the enormous force of 15 pounds upon every square inch; or above 2,000 pounds upon a square foot. This force would be insupportable to man and animals, were it not equal in all directions, entering into the pores of bodies, and thus being everywhere nearly in a state of equilibrium. It is only when we withdraw the air from a given space, so as to leave the surrounding air unbalanced, that we see marks of this violent pressure.

90. THE AIR-PUMP.—Various properties of the air are exhibited by this beautiful and interesting apparatus. A simple form of the Air-Pump is shown in fig-

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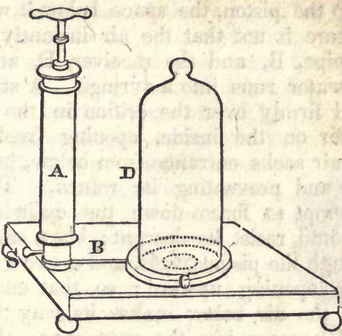
89. What is the pressure of the atmosphere upon a square inch, and square foot? Why is it not insupportable to man?

ure 43. A represents a cylinder having a piston moving up and down in it. The cylinder communicates by an open pipe, B, with the plate of the pump, C, opening into the receiver, D, which is a glass vessel ground at the bottom so as to fit the plate of the pump air-tight. At S is a small screw which opens or closes a passage into the pipe, B, by which air may be let into the receiver when it has been withdrawn by the pump.

Fig. 43.



In order to understand how the pump extracts the air from the receiver, or *exhausts* it, it is necessary first to learn the structure of a *valve*. A valve is any contrivance by which a fluid is permitted to flow one way, but prevented from flowing the opposite way. A common hand bellows affords an example of a valve, in the little clapper on the under side. When the bellows is opened, the clapper rises and the air runs in; and when the bellows is shut, the clapper closes

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90. Air-Pump. Describe Fig. 43. Describe a *valve*. Example in a bellows—in the piston and cylinder of the air-pump. Explain the

upon the orifice, and as the air cannot escape by the same way it entered, it is forced out by the nozzle of the bellows. In the bottom of the cylinder, A, in figure 43, there is a small hole, like a pin hole. On drawing up the piston, the space below it would be a vacuum were it not that the air instantly rushes in from the pipe, B, and the receiver, D, and fills the space, as water runs into a syringe. A strip of oiled silk is tied firmly over the orifice in the bottom of the cylinder on the inside, opening freely upward when this air seeks entrance from below, but shutting downward and preventing its return. Then if we should attempt to force down the cylinder, the air below it would resist its descent; but a small hole is made through the piston itself, and a valve tied to the upper side opening upward; so that on depressing the piston, the air below makes its way through the valve and escapes into the open space above. We raise the piston, and the air in the receiver follows it through a valve in the bottom of the cylinder opening upward. The original air of the receiver being now expanded equally through the receiver, the cylinder, and the connecting-pipe, we thrust down the piston, and the portion of the air that is contained in the cylinder is forced out through the piston. We again raise the piston, and the remaining air of the receiver expands itself as before through the vacuum; we depress the piston, and a second cylinder full of air is withdrawn. By continuing this process, we rarefy more and more the air of the receiver, every stroke of the piston leaving what remains more rare than before. Still, on account of the elasticity of air, what remains in the cylinder will always diffuse itself through the whole vessel, so that we cannot produce a complete vacuum by the air-pump.

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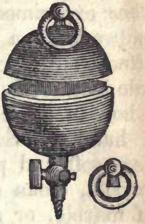
process of exhausting a vessel. Can we produce a complete vacuum by the air-pump?

91. Several experiments will illustrate the great *pressure of the atmosphere,* when no longer balanced by an equal and opposite force. We shall find the receiver, when exhausted by the foregoing process, held firmly to the plate of the pump so that we cannot remove it until we have opened the screw, S, and admitted the air; then the downward force of the air being counterbalanced by an equal force from within, the vessel is easily taken off. The *Magdeburg Hemispheres,* represented in figure 44, afford a striking illustration of the force of atmospheric pressure. When they have air within as well as without, they are easily, when joined, separated from each other; but let us now put them closely together and screw the ball thus formed upon the plate of the pump, exhaust the air, and close the stop-cock so as to prevent its return. We then unscrew the ball from the pump, and screw on the loose handle; the hemispheres are pressed so closely together that two men, taking hold by the opposite handles, can hardly pull them apart. Hemispheres four inches in diameter would be held together with a force equal to 188 pounds. Otto Guericke, of Magdeburg, in Germany, who invented the air-pump and contrived this experiment, had a pair of hemispheres constructed, so large that sixteen horses, eight on each side, were unable to draw them apart. A pair only two feet in diameter, would require to separate them a force equal to 6785 pounds. If our bodies were not so penetrated by air, that the external pressure is counterbalanced by an equal force from

Fig. 44.



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91. Give an example of the great pressure of the atmosphere. Describe the Magdeburg Hemispheres. What is said of those made by Otto Guericke? How much pressure does a middle-sized man sustain? Why are we not crushed?

within, we should be crushed under the weight of the atmosphere; for a middle sized man would sustain a pressure of about 14 tons.

92. If we take a *square bottle*, fit a stop-cock to it, and exhaust the air, the pressure on the outside will crush it into small fragments, with a loud explosion. It is prudent to throw a towel or handkerchief loosely over it, to prevent injury from the fragments. A *square* bottle is preferred to a round one, because such a figure has less power of resistance. The *lap-stone* experiment may be tried without an air-pump, and affords a pleasing illustration of the force of atmospheric pressure. Cut out a circular piece of sole leather, five or six inches in diameter. Through a hole in the center draw a waxed thread to serve as a handle. Soak the leather in water until it is very soft and pliable; then, on applying this to any smooth, clean surface, as that of a lap-stone, a slab of marble, or a table, it will adhere with such force, that we cannot lift it off; but when we pull upward, the heavy body to which it is attached will be lifted with it. We may, however, *slide* it with ease, because no force acts upon it to prevent its motion in this direction, except simply the adhesion of the surfaces. Flies are said to ascend a pane of glass on this principle, by applying their broad feet firmly to the glass, which are held down by the pressure of the atmosphere. When we apply a sucker, and exhaust it with the mouth, the fluid rises because

Fig. 45.

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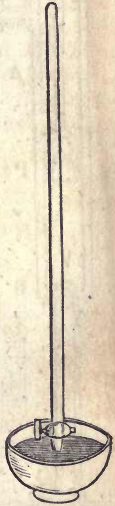
92. Describe the experiment with a square bottle. Also the lap-stone experiment. Why can we so easily *slide* the leather? How do flies ascend smooth planes? How does the boy suck water?

it is forced up by the pressure of the atmosphere on its surface. When we draw in the breath, the lungs are expanded like a pair of bellows. Thus the air runs from the sucker into the lungs, and forms a vacuum in the sucker. Immediately the pressure of the atmosphere on the surface of the fluid, not being balanced in the tube, forces the fluid up the tube and thence into the mouth.

93. If we fill a vial with water, and, placing one thumb on the mouth, invert it in a tumbler partly full of water, the water will not run out of the vial, but will remain suspended, because there being no air at the top of the column to balance the pressure that acts at the mouth of the vial, the column cannot descend. If, however, instead of the vial, we should employ a pipe more than 33 feet long, on filling it and inverting it, as was done with the vial, the water would settle to about 33 feet, and there it would rest; for the pressure of the atmosphere is capable of sustaining a column of water only 33 feet high. Were it higher than this, it would be more than a counterpoise for that pressure, and would overcome it and sink; and were it lower than that, it would be overcome by that pressure, and rise until it exactly balanced the force of the atmosphere. Instead of filling the pipe with water, we will attach a stop-cock to the open end, screw it on the plate of the air-pump, and exhaust the air. We will now close the stop-cock, and removing the tube

Fig. 46.



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93. Describe the experiment with the vial. Also with a pipe more than thirty-three feet long. If we exhaust the pipe and open it under water, what happens?

from the pump, will place the lower end of the pipe in a bowl of water. On opening the stop-cock the water will rush into the pipe, and rise to about the same height as before, namely, about 33 feet, where it will rest. In both cases, there is an empty space or vacuum in the upper part of the pipe above the column of water.

Fig. 47.

94. This experiment illustrates the principle of the *common pump*, of the *syphon*, and of the *barometer*. Let us first see how water is raised by the pump. This apparatus usually consists of two pipes—a larger, A B, above, and a smaller, H C, below. The piston moves in the larger pipe, and the smaller pipe descends into the well. On the top of the latter, where it enters the former, is a valve, V, opening upward. Suppose the piston, P, is down close to this valve. On raising it, the air from the lower pipe diffuses itself into the empty space below the piston, becomes rarefied, and no longer balances the pressure of the atmosphere on the surface of the well. Consequently, the water is forced up until the weight of the column, together with the weight of the rarefied air, restores the equilibrium. Suppose by the piston being drawn up to P, the water rises to H; then the column, H C, and the rarefied air in both pipes together, first counterbalance the weight of the atmosphere. On raising the piston still higher, the water rises above H, but would not probably reach the valve, V, by a single elevation of the pis-

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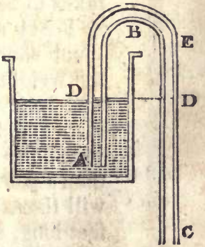
94. Explain the common pump from Fig. 47. How much force does the atmosphere exert in raising the water ?

ton. We therefore thrust down the piston to repeat the operation. The air between V and P is prevented from returning into the lower pipe, by the valve, V, which shuts downward; but the enclosed air, when compressed by the descending piston, lifts a valve in the piston, as in the air-pump, and escapes above. On drawing up the piston a second time, suppose that the water rises into the upper pipe above the valve, V, then on depressing the piston again, this water, pressed on by the piston, lifts its valve, and gets above it. Finally, on drawing up the piston again, this same water is lifted up to the level of the spout, S, where it runs off. We exert just as much force in exhausting the air, as the pressure of the atmosphere exerts in raising the water. It requires, therefore, just as much force to raise a given quantity of water by the pump, as to draw it up in a bucket; and the only question is, which is the most convenient mode of applying the force.

Fig. 48.



95. The *Syphon* is a bent tube, having one leg longer than the other, as in Fig. 48. If we dip the shorter leg into water and suck out the air from the tube, the water will rise, pass over the bend, flow out at the open end, and continue to run until all the water in the vessel is drawn off. Here the pressure of the atmosphere on both mouths of the tube is the same; but in each arm, that pressure is resisted by the weight of the column of water above it, and more by the longer than by the shorter column. This is the same thing as though the pressure were less upon the outer

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95. Describe the Syphon. Why does it draw off the liquid? State the uses of the Syphon. How high will it raise water?

than upon the inner mouth; and it is easy to see that if the water in a tube is pressed one way more than the other, it will flow in the direction in which the pressure is greatest. The syphon is used in drawing off liquors; and the water in aqueducts is sometimes conveyed over hills on the principle of the syphon. But we must remember, that water could not be raised by it more than 33 feet; for when the bend is 33 feet above the level of the fountain, then the column in the shorter arm balances the pressure of the atmosphere at the mouth of the tube in the well, and leaves no force to drive forward the column into the descending arm.

Fig. 49.

96. The *Barometer* is an instrument for measuring the pressure of the atmosphere. If the atmosphere be conceived to be divided into perpendicular columns, the barometer measures the weight of one of these by the height of a column of quicksilver which it takes to balance it. Quicksilver is 13½ times as heavy as water, and therefore a column so much shorter than one of water, will balance the weight of an atmospheric column. This will imply a column about 2½ feet, or 30 inches high; and it will be much more convenient to experiment upon such a column, than upon one of water 33 feet high. We will therefore take a glass tube about three feet long, closed at one end and open at the other, fill it with quicksilver, and placing the finger firmly on the open mouth, we will insert this below the surface of the fluid in the small cistern, as represented in the figure.

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96. Define the Barometer. Describe the mode of making it by Fig. 49. At what height will the quicksilver rest? What is the space above it called?

On withdrawing the finger, the quicksilver in the tube will settle to the height of about thirty inches, where it will rest, being sustained by the pressure of the atmosphere on the surface of the fluid in the cistern, to which force its weight is exactly equal. The space above the quicksilver, is the best vacuum we are able to form. It is called the *Torricellian* vacuum, from Torricelli, an Italian philosopher, who first formed it. The weight of a column of atmospheric air is different in different states of weather, and its variations will be indicated by the rising and falling of the quicksilver in the barometer. Any increase of weight in the air will make the fluid rise; any diminution of weight will make it fall. Hence, these variations in the height of the barometric column, show us the comparative weight and pressure of the atmosphere at any given time. By applying to the upper part of the tube a scale divided into inches and tenths of an inch, we can read off the exact height of the quicksilver at any given time. Thus, the fluid, as represented in the figure, stands at 29.4 inches.

97. The barometer is one of the most useful and instructive of philosophical instruments. By observing it from time to time, we may find how its changes are connected with the changes of weather, and thus it frequently enables us to foretell such changes. If, for example, we should observe a sudden and extraordinary fall of the barometer, we should know that a high wind was near, possibly a violent gale. To seafaring men, the barometer is a most valuable instrument, since it enables them to foresee the approach of a gale, and provide against it. As a general fact, the rising of the barometer indicates *fair*, and its falling, *foul* weather.

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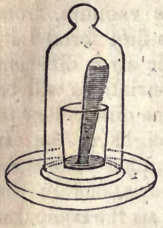
97. Explain the use of the barometer as a weather glass. What would a sudden and extraordinary fall indicate? What weather does its *rise*, and what its *fall* indicate?

98. The foregoing considerations relate to the weight and pressure of the atmosphere; but the air-pump also affords us interesting illustrations of the *elasticity* of air. We will fill a vial with water, and invert it in a tumbler partly filled with the same fluid. We will now place the tumbler and vial on the plate of the air-pump, and cover it with a receiver, and exhaust the air. Soon after we begin to work the pump, we shall see minute bubbles of air making their appearance in the water, which will rise and collect in a bubble at the top of the column. The bubble thus formed, will expand more and more as the exhaustion proceeds, until it expels the water, and occupies the whole interior of the vial. This will happen much sooner if we let in a bubble of air at first, and do not wait for it to be extricated from the water; but this extrication of air from the water, is itself an instructive part of the experiment, as it shows us that water contains a large quantity of air, held in combination with it by the pressure of the atmosphere on the surface, which pressure pervades all parts of the fluid alike. But on withdrawing this pressure gradually from the surface of the water, the particles of air imprisoned in the pores of the water escape, and collect on the top. The bubble thus formed, will expand more and more as the pressure is still farther removed, until it drives down the water and fills the whole vial. If we turn the screw S of the pump (Fig. 43) and let in the air, the pressure on the surface of the water in the tumbler being restored,

Fig. 50.



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98. Describe Fig. 50, and show how it illustrates the elasticity of air. What will porous bodies give out in an exhausted receiver? How will *warm* water be affected?

the water will be forced up the vial again, and the air will be reduced to its original bubble. If we place any porous substance, as a piece of brick, or a crust of bread, in a tumbler, and fill the tumbler with water, (attaching a small weight to the bread to keep it under) we shall see, in like manner, an unexpected amount of air extricated when we place it under the receiver, and remove the atmospheric pressure from it, so as to permit it to assume the elastic state. Liquids boil at a much lower temperature than usual, when the pressure of the atmosphere is removed from them. Thus, if we take a tumbler half full of water, no more than blood-warm, set it under the receiver, and exhaust the air, it will boil violently.

99. Air is the medium of *combustion*, of *respiration*, and of *sound*. If we place a lighted candle under the receiver of an air-pump, and exhaust the air, the light will immediately go out, showing that bodies cannot burn without the presence of air. Nor without this can animals breathe. A small bird placed beneath the receiver, will cease to breathe as soon as the air is exhausted. If a bell, also, is made to ring under a receiver, the sound will grow fainter and fainter as the air is withdrawn, and finally be scarcely heard at all. The *buoyancy* of air, like that of water, enables it to support light bodies. In a vacuum, the heaviest and lightest bodies descend to the earth with the same velocity. If we suspend a guinea and a feather from the top of a tall receiver, exhaust the air, and let them fall at the same instant, the feather will keep pace with the guinea, and reach the plate of the pump at the same instant.

100. THE CONDENSER.—A piston and cylinder may be so contrived as to pump air into a vessel instead of

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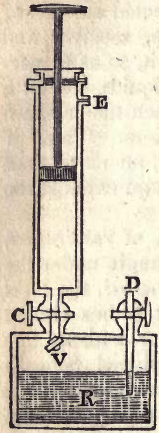
99. How may we show that air is essential to combustion? Also to life? Also to sound? Describe the guinea and feather experiment

pumping it out. Figure 51 represents a condensing syringe, screwed to a box partly filled with water. When the piston is drawn up to the top, above an orifice E in the side, the air runs in at E, which on depressing the piston, is driven forward into the box through a valve, V, which opens inward, but closes outward, and prevents the return of the air. By repeated blows of the piston, more and more air is forced into the box, constantly increasing the pressure on the surface of the water. D is a tube opening and closing by a stop-cock, having its lower end in the water. When the air is strongly condensed, on opening the stop-cock, the water issues from the tube with violence. *Soda Water Fountains* are constructed on this principle. A great quantity of carbonic acid, or fixed air, is forced into a strong metallic vessel, containing a solution of soda, and therefore is subjected to a powerful pressure. A tube connects this vessel to the counter where the liquor is to be drawn, which issues with violence, as soon as vent is given to it, and foams, in consequence of the carbonic acid expanding by the removal of the pressure by which it had been confined. The condenser employed for this purpose, is called a *forcing pump*, and differs from the condensing syringe, represented in figure 51, chiefly in being worked by a lever attached to the piston, instead of the naked hand.

Fig. 51.



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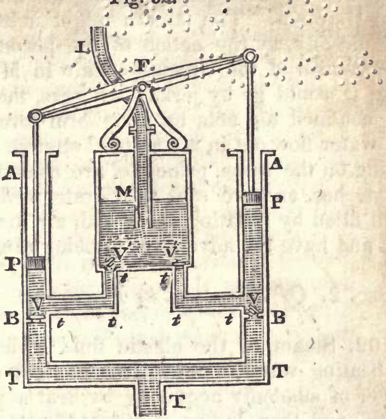
100. Describe the Condenser from Fig. 51. How is air pumped into the box? Explain the principle of soda water fountains. What is the forcing pump?

Fig. 52.



101. The *Fire-Engine* throws water by means of two forcing pumps, one on each side, which are worked by the firemen. T represents the hose, or leathern pipe, which leads off to some well or cistern of water, whence the supply is drawn. F is the working beam, to each end of which is attached a piston moving in the cylinder A B. Suppose at the commencement of the process, the left hand piston is down close to the valve V; as it rises, the water follows it from the hose, lifting the valve V, and entering P B below the piston. When the piston descends, it forces the water through a valve into the air-vessel, M. As the water is thrown in by successive descents of the piston, it rises in M, and condenses the air of the vessel into a small space at the top. A second hose, F, dips into the water, and terminates in the farther end in a pipe, which the fireman directs

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101. Describe the fire-engine from Fig. 52. Why is the air-vessel used? Use of air-springs and air-beds?

upon any required point, sending the water in a continual stream. The stream might indeed be propelled directly by the action of the pistons, without the intervention of the compressed air in M; but in that case it would go by jerks; whereas, the elasticity of the confined air acts as a uniform force, and makes the water flow out in a continual stream. *Air-springs*, acting on the same principle, are sometimes attached to coaches, and are said to operate well. *Beds* have been filled by inflating them with air instead of feathers, and have the advantage of being always made up.

Sec. 2. *Of Steam and its Properties.*

102. Steam, or the elastic fluid which is produced by heating water, owes its mechanical efficacy to its power of suddenly acquiring by heat a powerful elasticity, and then losing it as suddenly, by cold; in the former case, expanding rapidly, and expelling every thing else from the space it occupies; and, in the latter case, shrinking instantly to its original dimensions in the state of water, and thus forming a vacuum. By this means, an alternate motion is given to a piston, which being communicated to machinery, supplies a force capable of performing every sort of labor, and being easily endued with any required degree of energy, is at once the most efficient and the most manageable of all the forces of nature. Thus, if steam be admitted below the piston, in figure 53, when its force accumulates sufficiently to overcome the resistance of the piston, it raises it; and if it then be let in above the piston, it depresses it. When the piston rises, it may be made to turn a crank half round, and the other half when it falls, and thus a

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102. To what two properties does steam owe its mechanical efficacy? To what is the motion first communicated, and how transferred to machinery? Show how the piston is raised and depressed.

main wheel may be made to revolve, from which motion may be conveyed to all sorts of machinery. The degree of force which steam exerts, depends on the *temperature* and *density* conjointly. If we put a spoonful of water into a convenient vessel, as an oil-flask, and place it over the fire, the water will soon be turned into elastic vapor, which will drive out the air and fill the entire capacity of the vessel. As soon as this takes place, we cork the flask and again set it over the fire. The steam will increase in elastic power, just as that of air would do, which is only at a moderate rate, and it might be heated red hot without exerting any violent force. If we now unstop the flask and fill it one third full of water, and again place it on the fire, and stop it close when it is boiling freely, then successive portions of water will be constantly passing into vapor, and, of course, the steam in the upper part of the vessel will be constantly growing more and more dense. It is important to remember, therefore, that when steam is heated by itself, and not in contact with water, its elasticity increases slowly, and never becomes very great; but when it is heated in a close vessel containing water, which makes to it constant additions of vapor, thus increasing its density, it rapidly acquires elastic force, and the faster the longer the heat is continued, so as shortly to reach an energy which nothing can resist. Such an accumulation of force sometimes takes place by accident in a steam boiler, and produces, as is well known, terrible explosions.

103. If the foregoing principles are well understood, it will be easy to learn the construction and operation of the *Steam Engine*. For the sake of simplicity, we will leave out numerous appendages which

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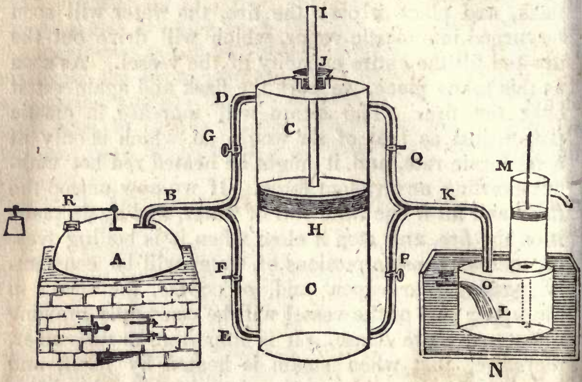
Upon what does the degree of force depend? Experiment with a flask of steam with and without water.

usually accompany this apparatus, but are not essential to the main principle. In figure 53, A represents

Fig. 53.



the *boiler*, C the *cylinder*, in which the piston H moves, L the *condenser*, and M the *air-pump*. B is the *steam-pipe*, branching into two arms, communicating respectively with the top and bottom of the cylinder, and K is the *eduction-pipe*, formed of the two branches which proceed from the top and bottom of the cylinder on the other side, and communicate between the cylinder and the condenser, which is immersed in a well or cistern of cold water. Each branch of the pipe has its own valve, as F, G, P, Q, which may be opened or closed as occasion requires. R is a safety valve, closed by a plate, which is held down by a weight attached to a lever, and sliding on it, so as to increase or diminish the force at pleasure. When

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103. Describe Figure 53.

the force of the steam exceeds this, it will lift the valve and escape, thus preventing the danger of explosion.

104. Suppose, first, that all the valves are open, and that steam is issuing freely from the boiler. It is easy to see, that the steam would circulate freely through all parts of the engine, expelling the air, which would escape through the valve in the piston of the air-pump, and thus the interior spaces would be all filled with steam. This process is called *blowing off;* it is heard when a steamboat is about leaving the wharf. Next the valves, F and Q, are closed, G and P remaining open. The steam now pressing on the cylinder, forces it down, and the instant when it begins to descend, the stop-cock O is opened, through which cold water meets the steam as it rushes from the cylinder and condenses it, leaving no force below the piston to oppose its descent. Lastly, G and P being closed, F and Q are opened, the steam flows in from the boiler below the piston, and rushes from above into the condenser, by which means the piston is forced up again with the same power as that by which it descended. Meanwhile, the air-pump is playing, and removing the water and air from the condenser, and pouring the water into a reservoir, whence it is conveyed to the boiler to renew the same circuit.

105. In *High Pressure* engines, the steam is not condensed, but discharges itself directly into the atmosphere. The *puffing* heard in locomotives, arises from this cause. High pressure engines are those in which steam of great density, and high elastic power, is used. By this means, a more concentrated force is produced, and the engine may be smaller and more compact;

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104. Show how the engine is set a going, and kept at work.

105. What becomes of the steam in high pressure engines? Whence arises the puffing heard in locomotives? What are high pressure engines? What are their advantages over low pressure engines?

but unless it is made proportionally stronger, it is more liable to explode, and when it gives way it explodes with great violence.

CHAPTER V.

METEOROLOGY.

GENERAL OBJECTS OF THE SCIENCE—EXTENT, DENSITY, AND TEMPERATURE OF THE ATMOSPHERE—ITS RELATIONS TO WATER—RELATIONS TO HEAT—RELATIONS TO FIERY METEORS.

106. METEOROLOGY *is that branch of Natural Philosophy which treats of the Atmosphere.* In Pneumatics, we learn the properties of elastic fluids in general, on a small scale, and by experiment rather than by observation; but in Meteorology, we extend our views to one of the great departments of nature, and we reason, from the known properties of air and vapor, upon the phenomena and laws of the entire body of the air, or the atmosphere. Meteorology leads us to consider, first, the *description* of the atmosphere itself, including its extent, condition at different heights, and the several elements that compose it; secondly, the relations of the atmosphere to *water*, including the manner in which vapor is raised into the atmosphere, the mode in which it exists there, and the various ways in which it is precipitated in the form of dew, fog, clouds, rain, snow, and hail; thirdly, the relations of the atmosphere to *heat*, embracing the motions of the atmosphere as exhibited on a small scale, in artificial draughts and ventilation; and on a large scale, in winds, hurricanes, and tornadoes;

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106. Define Meteorology. How distinguished from Pneumatics? What different subjects does Meteorology lead us to consider?

finally, in the relations of the atmosphere to *fiery meteors*, as thunder and lightning, aurora borealis, and shooting stars.

SEC. 1. *Of the Extent, Density, and Temperature of the Atmosphere.*

107. The atmosphere is a thin transparent veil, enveloping the earth, and extending to an uncertain height, but probably not less than one hundred miles above it. Since air is elastic, and the lower portions next to the earth sustain the weight of the whole body of air above them, they are compressed by the load, as air would be under any other weight. As we ascend above the earth, the air grows thinner and thinner very fast, so that if we could rise to the height of seven miles in a balloon, we should find the air four times as rare there as at the surface of the earth. The air is, indeed, much more rare on the tops of high mountains than at the level of the sea; and at a height much greater than that of the highest mountains on the globe, man could not breathe, nor birds fly. The upper regions of the atmosphere are also very *cold*. As we ascend high mountains, even in the torrid zone, the cold increases, until we finally reach a point where water freezes. This is called the *term of congelation*. At the equator, it is about three miles high; but in the latitude of 40, it is less than two miles, and in the latitude of 80, it is only one hundred and twenty feet high. Above the term of congelation, the cold continues to increase till it becomes exceedingly intense. The clouds generally float below the term of congelation. Mountains, when very high, are usually covered with snow all the year round, even in the

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107. Give a general description of the atmosphere, as to its height—density at different heights—cold of the upper regions. What is the term of congelation? How high at the equator? At 40° and 80°?

warmest countries, merely because they are above this boundary.

SEC. 2. *Of the Relations of the Atmosphere to Water.*

108. Besides common air, the atmosphere always contains more or less watery vapor, a minute portion of fixed air, or carbonic acid, and various exhalations, which are generally too subtile to be collected in a separate state. By the heat of the sun, the waters on the surface of the earth are daily sending into the atmosphere vast quantities of watery vapor, which rises not only from seas and lakes, but even from the land, wherever there is any moisture. The vapor thus raised, either mixes with the air and remains invisible, or it rises to the higher and colder regions, and is condensed into clouds. Sometimes accidental causes operate to cool it near the surface of the earth, and then it forms fogs. It returns to the earth in the forms of dew, and rain, and snow, and hail.

109. *Dew* does not fall from the sky, but is deposited from the air on cold surfaces, just as the film of moisture is, which we observe on a tumbler of cold water in a sultry day. Here, the air coming in contact with a surface colder than itself, has a portion of the invisible vapor contained in it condensed into water. In the same manner, on clear and still nights, which are peculiarly favorable to the formation of dew, the ground becomes colder than the air, and the latter circulating over it, deposits on it and on all things near it, a portion of its moisture. Dew does not form on all substances alike that are equally ex-

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108. What other elastic fluids besides air does the atmosphere contain? Whence is the watery vapor derived? What becomes of it?

109. How is dew formed? Does dew form on all substances alike? What receive the most? What receive none?

posed to it. Some substances on the surface of the earth are found to grow colder than others, and these receive the greatest deposit of dew. Deep water, as that of the ocean, does not grow at all colder in a single night, and therefore receives no dew; and the naked skins of animals, being warmer than the air, receive none; although the moisture which is constantly exhaled from the animal system itself, as soon as it comes into contact with the colder air that surrounds the person, may be condensed, and moisten the skin or the clothes in such a way as to give the appearance of dew. In this manner, also, frost (which is nothing more than frozen dew) collects, in cold weather, on the bodies of domestic animals. By a beautiful provision of Providence, dew is always guided with a frugal hand to those objects which are most benefited by it. Green vegetables receive much more than naked sand equally exposed, and none is squandered on the ocean.

110. *Rain* is formed in the atmosphere at some distance above the earth, where warm air becomes cooled. If it is only cooled a few degrees, the moisture may merely be condensed into cloud; but if the cooling is greater, rain may result; and when a hot portion of air, containing, as such air does, a great quantity of watery vapor in the invisible state, is suddenly cooled by any cause, the rain is more abundant, or even violent. In such cases, it may have been cooled by meeting with a portion of colder air, as when a warm southwesterly wind meets a cold northwester, or by rising into the upper regions near the term of congelation. In some parts of the earth, as in Egypt, and in a part of Chili and Peru, it seldom or never rains, for there the winds usually blow

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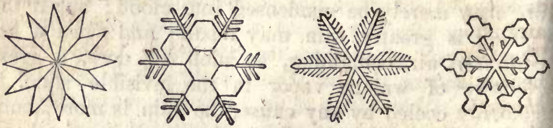
110. Where is rain formed, and how? When is the precipitation in the form of cloud? When of rain? When is the rain violent? In

steadily in one direction, and encounter none of those mixtures with colder air which form rain. In some other countries, as the northeastern part of South America, the rains are excessive; and in others, as most tropical countries, the rains are periodical, being very copious at particular periods called the rainy seasons, while little or none falls during the other parts of the year.

111. *Snow* is formed from vapor crystallized by cold instead of uniting in drops. By this means it is converted into a light downy substance, which falls gently upon the earth, and forms a covering that confines the heat of the earth, and furnishes an admirable defence of the vegetable kingdom, during winter, in severe climates. In cold climates, flakes of snow consist of regular crystals, presenting many curious figures, which, when closely inspected, appear very beautiful. Nearly a hundred distinct forms of these crystals have been particularly described by voyagers in the polar seas, specimens of which, as they appear under the magnifier, are exhibited in the following diagram.

Fig. 54.



When a body of hot air becomes suddenly and intensely cooled, the watery vapor is frozen and forms *hail*. The most violent hailstorms are formed by whirlwinds, which carry up bodies of hot air far beyond the term of congelation, where the drops of

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what different ways is the hot air cooled? Where does it never rain? Why? Where are the rains excessive? Where periodical?

111. Snow, how formed? What purpose does it serve? In what manner does it crystallize, and in how many different forms? When is hail formed? How are the most violent hailstorms formed? How

rain are frozen into hailstones, and these being sustained for some time by the upward force of the whirlwind, accumulate occasionally to a very large size. Hailstorms are chiefly confined to the temperate zones, and seldom occur either in the torrid or the frigid zone. In the equatorial regions, the term of congelation is so high, that the hot air of the surface, if raised by a whirlwind, would seldom rise beyond it; and in the polar regions, the air does not become so hot as is required to form a hailstorm.

SEC. 3. *Of the Relations of the Atmosphere to Heat.*

112. It is chiefly by the agency of heat, that air is put in motion. If a portion of air is heated more than the surrounding portions, it becomes lighter, rises, and the surrounding air flows in to restore the equilibrium; or if one part be cooled more than another, it contracts in volume, becomes heavier, and flows off on all sides until the equilibrium is restored. Thus the air is set in motion by every change of temperature; and as such changes are constantly taking place, in greater or less degrees, the atmosphere is seldom at rest at any one place, and never throughout any great extent. The most familiar example we have of the effects of heat in setting air in motion, is in the *draught of a chimney*. When we kindle a fire in a fireplace, or stove, it rarefies the air of the chimney, and the denser air from without rushes in to supply the equilibrium, carrying the smoke along with it. Smoke, when cooled, is heavier than air, and tends to descend, and does descend unless borne up by a current of heated air. A

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do hailstones acquire so large a size? To what regions are hailstorms chiefly confined? Why do they not occur in the torrid and frigid zones?

112. By what agent is air put in motion? Describe the process. How is the draught of a chimney caused? Why does smoke ascend?

hot current of air in a chimney is cooled much more rapidly when the materials of the chimney are damp than when they are dry, and therefore it will cool much faster in a wet than in a dry atmosphere. Hence, chimneys are apt to smoke in wet weather. It is essential to a good draught, that the inside of a chimney should be smooth, for air meets with great resistance in passing over rough surfaces. Burning a chimney improves the draught, principally by lessening the friction occasioned by the soot. In stoves for burning anthracite coal, it is important to the draught, that no air should get into the chimney except what goes through the fire. On account of the great resistance which a thick mass of anthracite opposes to air, this will not work its way through the coal if it can get into the chimney by any easier route. Hence the pipes which conduct the heated air from a stove to the chimney, should be close, especially the joint where the pipe enters the chimney; and care should be taken, that there should be no open fireplace, or other means of communication, between the external air and the flue with which the stove is connected.

113. It is important to health, that the apartments of a dwelling-house should be well *ventilated.* This is especially the case with crowded rooms, such as churches and schoolhouses. Of the method of ventilating churches, a beautiful specimen is afforded in the Centre church, in New Haven. In the middle of the ceiling, over the body of the church, is an opening through the plastering, which presents to the eye nothing but a large circular ornament in stucco. Over this, in the garret of the building, a circular enclosure of wood is constructed, on the top of which is built a

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Why do chimneys smoke in wet weather? Why should a chimney be smooth? Why does burning a chimney improve the draught? What precautions are necessary in burning anthracite coal, in order to secure a good draught?

large wooden chimney, leading off, at a small rise, to the end of the building, where it enters the steeple. An upper window of the steeple being open, in warm weather, the current sets upward from the church into the chimney, and thence into the tower, and completely ventilates the apartment below. A door, so hung as to be easily raised or lowered by a string, leading to a convenient place at the entrance of the church, can be opened or closed at pleasure. In cold weather, it will generally be found expedient to keep it closed, to cut off cold air, opening it only occasionally. A schoolhouse may easily be ventilated by a similar contrivance connected with a belfry over the center, as is done in several schoolhouses recently built in New England.

114. Nature, however, produces movements of the atmosphere on a far grander scale, in the form of *Winds*. These are exhibited in the various forms of breezes, high winds, hurricanes, gales, and tornadoes; varieties depending chiefly on the different velocities with which the wind blows. A velocity of twelve miles an hour makes a strong breeze; sixty miles, a high wind, one hundred miles, a hurricane. In some extreme cases, the velocity has been estimated as high as three hundred miles an hour. The force of the wind is proportioned to the square of the velocity; a speed ten times as great increases the force a hundred times. Hence, the power of violent gales is irresistible. Air, when set in motion, either on a small or on a great scale, has a strong tendency to a whirling motion, and seldom moves forward in a straight line. The great gales of the ocean, and the smal.

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113. Ventilation, in what cases is it important? How effected in churches—how in schoolhouses?

114. Specify the different varieties of winds. State the velocity of a breeze—of a high wind—of a hurricane. How is the force of a wind proportioned to the velocity? Tendency of air to a whirling motion

tornadoes of the land, often, if not always, exhibit more or less of a rotary motion, and sometimes appear to spin like a top around a perpendicular axis, at the same time that they advance forward in some great circuit.

115. METEOROLOGICAL INSTRUMENTS.—The principal of these are the Thermometer, the Barometer, and the Rain Gage. The principle, construction, and uses of the *Barometer*, have already been pointed out, (Arts. 96 and 97.) Since it informs us of the changes that take place in the weight and pressure of the atmosphere, at any given place, on which depend most of the changes of weather, it becomes of great aid in the study of Meteorology, and has, in fact, led to the knowledge of most of the laws of atmospheric phenomena hitherto established. We should, in purchasing, be careful to select an instrument of good workmanship, for no other is worthy of confidence. We should suspend it in some place where there is a free circulation of air—as in an open hall, having an outside door—and we should take the exact height of the mercury at the times directed below for recording the thermometrical observations. In case the barometer is falling or rising with unusual rapidity, observations should be recorded every hour, or even oftener, as such observations afford valuable means of comparison of the states of the atmosphere at different places.

116. The *Thermometer* is an instrument used for measuring variations of temperature by its effects on the height of a column of fluid. As heat expands and cold contracts all bodies, the amount of expansion or contraction in any given case, is made a criterion of

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115. What are the three leading meteorological instruments? Great value of the barometer. Rules for selecting a barometer and for observing.

116. For what is the thermometer used? What shows the change

the change of temperature. Fahrenheit's thermometer, the one in common use, consists of a small glass tube, called the stem, with a bulb at one end, and a scale at the side. The bulb and a certain part of the stem are filled with mercury. The scale is divided into degrees and aliquot parts of a degree. If we dip the thermometer into boiling water, the mercury will expand and rise in the stem to a certain height, and there remain stationary. We will, therefore, mark that point on the stem, and then transfer the thermometer to a vessel where water is freezing. The mercury now descends to a certain level, and remains there stationary, as before. We mark this point, and we thus obtain the two most important fixed points on the scale, namely, the freezing and boiling points of water. We will now apply the scale, and transfer these marks from the stem to the scale, and divide the part of the scale between them into 180 equal parts, continuing the same divisions below the freezing point 32 degrees, where we make the zero point, and there begin the graduation from 0 to 32, the *freezing* point, and so on 180 degrees more, to 212, the *boiling* point.

The best times for making and recording observations, are when the mercury is lowest, which occurs about sunrise, and when it is highest, which is near two o'clock in winter, and three in summer. The sum of these observations, divided by two, gives the average, or *mean*, for the twenty-four hours; the sum of the daily means for the days of a month, gives the mean for that month; and the monthly averages, divided by twelve, give the annual mean. By such observations, any one may determine the temperature of the place where he resides.

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of temperature? Describe Fahrenheit's thermometer. How do we ascertain the boiling and freezing points of water? Into how many degrees is the space between them divided? Where is the zero point, and at what degrees are the freezing and boiling points? How to find the daily, monthly, and annual means?

117. The climate of the United States is very variable, and the annual range of the thermometer is greater than in most other countries. It embraces 140°, extending from 40° below zero, (usually marked —40°,) to 100° above. In the southern part of New England, the mercury seldom rises above 90,° and descends but a few times in the winter below zero. From 70° to 80° is a moderate summer heat. Although the equatorial regions of the earth are, in general, hotter than places either north or south, yet we have seen that the temperature of a place depends on various other circumstances, as well as on the latitude. (Arts. 82 and 107.)

Fig. 55.

118. The *Rain Gage* is an instrument employed for ascertaining the amount of water that falls from the sky, in the various forms of rain, snow, and hail. The simplest form is a tall tin cylinder, with a funnel-shaped top, having a graduated glass tube communicating with the bottom, and rising on the side. The water will stand at the same level in the tube and in the cylinder, and the divisions of the tube may be such as to indicate minute parts of an inch, and thus determine the depth of rain that falls on the area of the funnel, suppose a square foot. After the rain is over, the water may be removed by means of the stop-cock, and the apparatus will be ready for a new observation. It is useful to know the amount of rain that falls annually at any given place, not only in reference to a knowledge of the climate, but also for many practical purposes to which water is applied,

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117. What is said of the climate of the United States? What is the annual range of the thermometer? In New England, what is the range? What is a moderate summer heat?

118. What is the Rain Gage? Explain the simplest form. How to find the amount of rain fallen? Why is it useful to know the amount of rain that falls?

such as feeding canals, turning machinery, or irrigating land.

Sec. 4. *Of the Relations of the Atmosphere to Fiery Meteors.*

119. The luminous phenomena which go under the general name of "fiery meteors," are Thunder Storms, Aurora Borealis, and Shooting Stars. Sudden and violent showers of rain, in hot weather, are usually accompanied by thunder and lightning. The lightning is owing to the sudden discharge of electricity, and the thunder is ascribed to the rushing together of the opposite portions of air, that are divided by the passage of the electric current. The snapping of a whip depends on the same principle as a clap of thunder. The lash divides the air, and the forcible meeting of the opposite parts to restore the equilibrium, produces the sound. Whenever hot vapor is rapidly condensed, a great amount of electricity is extricated. This accumulates in the cloud, until it acquires force enough to leap from that to some other cloud, or to the earth, or to some object near it, and thus the explosion takes place.

120. The *Aurora Borealis*, or *Northern Lights*, are most remarkable in the polar regions, and are seldom or never seen in the torrid zone. They sometimes present merely the appearance of a *twilight* in the north; sometimes they shoot up in *streamers*, or exhibit a flickering light, called *Merry Dancers;* sometimes they span the sky with luminous *arches*, or bands; and more rarely they form a circle with stream-

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119. What are the three varieties of fiery meteors? How is lightning produced? To what is thunder ascribed? How explained by the snapping of a whip? Origin of the electricity of thunder storms? When does an explosion take place?

120. Aurora Borealis, where most remarkable? Specify the sev-

ers radiating on all sides of it, a little southeast of the zenith, called the *corona*. The aurora borealis is not equally prevalent in all ages, but has particular periods of visitation, after intervals of many years. It is more prevalent in the autumnal months than the other parts of the year, and usually is most striking in the earlier parts of the night, frequently kindling up with great splendor about 11 o'clock. From 1827 to 1842, inclusive, was a remarkable period of auroras. The cause of this phenomenon is not known; it has been erroneously ascribed to electricity, or magnetism; but it is probably derived from matter found in the planetary spaces, with which the earth falls in while it is revolving around the sun.

121. *Shooting Stars* are fire-balls which fall from the sky, appearing suddenly, moving with prodigious velocity, and as suddenly disappearing, sometimes leaving after them a long train of light. They are occasionally observed in great numbers, forming what are called *Meteoric Showers*. Two periods of the year are particularly remarkable for these displays, namely, the 9th or 10th of August, and the 13th or 14th of November. The most celebrated of these showers occurred on the morning of the 13th of November, 1833, when meteors of various sizes and degrees of splendor, descended with such frequency as to give the impression that the stars were all falling from the firmament. The exhibition was nearly equally brilliant in all parts of North America, and lasted from about 11 o'clock in the evening till sunrise. This phenomenon began to appear in some parts of the world, as early as November, 1830, and increased

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eral varieties. Is it equally prevalent in all ages? What was a remarkable period? Is its cause known? To what has it been ascribed? In what part of the year is it most frequent?

121. What are shooting stars? What two periods of the year are remarkable for their occurrence? When did the greatest meteoric

in splendor at the same period of the year, every year, until 1833, when it reached its greatest height. It was repeated on a smaller scale, every year, until 1838, since which time nothing remarkable has been observed at this period. The meteoric shower of August still (1843) continues. Meteoric showers appear to rise from portions of a body resembling a comet, which revolves about the sun, and sometimes comes so near the earth that portions of it are attracted down to the earth, and are set on fire as they pass through the atmosphere.

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CHAPTER VI.

ACOUSTICS.

VIBRATORY MOTION—VELOCITY OF SOUND—REFLEXION OF SOUND—MUSICAL SOUNDS—ACOUSTIC TUBES—STETHOSCOPE.

122. Acoustics (a term derived from a Greek word which signifies *to hear*) *is that branch of Natural Philosophy which treats of Sound.* Sound is produced by the vibrations of the particles of a sounding body. These vibrations are communicated to the air, and by that to the ear, which is furnished with a curious apparatus specially adapted to receive them and convey them to the brain, and thus is excited the sensation of hearing. Vibration consists in a motion of the particles of a body, *backward and forward*, through an exceedingly minute space. The particles of air in contact with the body, receive a corresponding motion, each particle impels one before it, and re-

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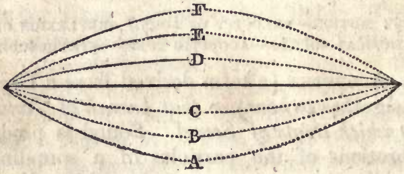
shower occur? Describe this shower. Whence do meteoric showers arise?

122. Define Acoustics. How is sound produced? In what does vibration consist? Does it imply a progressive motion? What bo-

bounds, and thus the motion is propagated from particle to particle, from the sounding body to the ear. Such a vibratory motion of the medium, does not imply any current or progressive motion in the medium itself, but each particle recovers its original situation when the impulse that produced its vibration ceases. Elastic bodies being most susceptible of this vibratory motion, are those which are usually concerned in the production of sound. Such are thin pieces of board, as in the violin; a steel spring, as in the Jewsharp; a glass vessel, and cords closely stretched; or a column of confined air, as in wind instruments. If we stretch a fine string between two fixed points, and draw it out of a straight line to A, and then let it go, it will proceed to nearly the same distance on the other side, to E, whence it will return to B, and thus continue to vibrate through smaller and smaller spaces, until it comes to a state of rest. When we throw a stone upon a smooth surface of water, a circle is raised immediately around the stone; that raises another circle next to it, and this another beyond it, and thus the original impulse is transmitted on every side. This example may give some idea of the manner in which sound is propagated through the air in all directions from the sounding body.

Fig. 56.



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dies are most susceptible of vibration? Give examples. Describe Fig. 56. What takes place when a stone is thrown on water?

123. Although air is the usual medium of sound, yet it is not the only medium. Solids and liquids, when they form a direct communication between the sounding body and the ear, conduct sound far better than air. When a tea-kettle is near boiling, if we apply one end of an iron poker to the kettle, and put the other end to the ear, we may perceive when the water begins to boil, long before it gives the usual signs. If we attach a string to the head of a fire-shovel, and winding the ends around the fore fingers of both hands, apply them to the ears, and then ding the shovel against an andiron, or any similar object, a sound will be heard like that of a heavy bell. The ticking of a watch may be heard at the remote end of a long pole, or beam, when the ear is applied to the other end; and if the watch is let down into water, its beats are distinctly heard by an ear placed at the surface. A bell struck beneath the water of a lake, has been heard at the distance of nine miles. Air is a better conductor of sound when moist than when dry. Thus, we hear a distant bell or a waterfall with unusual distinctness just before a rain, and better by night than by day. Air conducts sound better when condensed, and worse when rarefied. On the tops of some of the high mountains of the Alps, where the air is much rarefied, the sound of a pistol is like that of a pop-gun.

124. The *velocity* of sound in air is 1130 feet in a second, or a little more than a mile in five seconds. On this principle, we may estimate the distance of a thunder-cloud, by the interval between the flash and the report. For example, an interval of five seconds, gives 1130×5=5650 feet, or a little more than a mile. A feeble sound moves just as fast as a loud one. Its

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123. Is air the only medium of sound? Conducting power of solids and liquids? Experiment with a tea-kettle—with a fire-shovel—with a watch. Conducting power of moist air?—Of rarefied air?

124. Velocity of sound. How to estimate the distance of a thunder

velocity is not altered by a high wind in a direction at right angles to the course of the wind; but in the same direction, the comparatively small velocity of the wind is to be added, and in the opposite direction to be subtracted. In water, the velocity of sound is about four times as great as in air, being 4709 feet per second; and in cast iron its velocity is more than ten times as great as in air, being no less than 11,895 feet per second.

125. Sound is capable of being *reflected*, and is thus sometimes returned to the ear, forming an *echo*. Thus, the sound of the human voice is sometimes returned to the speaker, or other persons near him, in a repetition usually somewhat feebler than the original sound; but it may be louder than that, if several reflected waves are unitedly conveyed to the ear. When one stands in the centre of a hollow sphere or dome, numerous waves being reflected from the concave surface so as to meet in the centre, a sound originally feeble becomes so augmented as to be astounding. A cannon discharged among hills or mountains, reverberates in consequence of the repeated reflexions of the sound.

126. A sound becomes *musical* when the vibrations are performed with a certain degree of frequency. The slow flapping of the wings of a domestic fowl has nothing musical; but the rapid vibration of the wings of a humming-bird, produces a pleasant note. The slow falling of trees before a high wind, is attended with a disagreeable crash; the rapid prostration of the trees of a forest by a tornado, with a sublime roar. A string stretched between two points, and made to

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cloud? Velocity of a *feeble* sound—effect of a high wind? Velocity of sound in water?

125. Echo, how produced—when louder than the original sound? Effect of a dome—of a cannon among hills?

126. How a sound becomes musical?—examples in the wings of birds—in falling trees—in a vibrating string. How does increasing

vibrate very slowly, has nothing musical; but when the tension is increased, and the vibrations quickened, the note grows melodious. The strings of a violin give different sounds in consequence of affording vibrations more or less rapid. The larger strings, having slower vibrations, afford graver notes. The screws enable us to alter the degree of tension, and thus to increase or diminish the number of vibrations at pleasure; and by applying the fingers to the strings, we can shorten them more or less, producing sounds more or less acute, by increasing the number of vibrations in a given time. In wind instruments, as the flute, the vibrating body which produces the musical tone is the column of air included within. This, by the impulse given by the mouth, is made to vibrate with the requisite frequency, which is varied by opening or closing the stops with the fingers. The shorter the column, the more rapid is the vibration, and the more acute the sound; and the length of the vibrating column is determined by the place of the stop that is opened, the higher stops giving sharper sounds because the vibrating columns are shorter. The pipes of an organ sound on a similar principle, the wind being supplied by a bellows instead of the breath. In certain instruments, as the clarinet and hautboy, the vibrations are first communicated from the lips of the performer to a reed, and from that to the column of air.

127. Sounds differing from each other by certain intervals, constitute musical *notes*. The singing of birds affords sweet sounds but no music, being uttered continuously and not at intervals. Man only, among animals, has the power of uttering sounds in this man-

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the tension, the size, or the length of the string, affect the pitch? Example in the violin. What produces the musical tone in wind instruments? Why does opening or closing the stops, alter the pitch? Explain the use of a reed.

127. What sounds constitute musical notes? Why is not the singing of birds music? Why is man alone capable of uttering musical

ner; and his voice alone, therefore, is endued with the power of music. Music becomes a branch of mathematical science, in consequence of the relation between musical notes, and the *number of vibrations* that produce them respectively. Although we cannot say that one sound is larger than another, yet we can say that the vibrations necessary to produce one sound are twice or thrice, or any number of times, more frequent than those of another; and the number of vibrations necessary to produce one note has a fixed ratio to the number which produces another note. Thus, if we diminish the length of a musical string one half, we double the number of vibrations in a given time, and it gives a sound eight notes higher in the scale than that given by the whole string, and is called an octave. Hence, these sounds are said to be to each other in the ratio of 2 to 1, because this is the ratio of the numbers of vibrations which produce them. A succession of single musical sounds constitutes *melody;* the combination of such sounds, at proper intervals, forms *chords;* and a succession of chords, produces *harmony.* Two notes formed by an equal number of vibrations in a given time, and of course giving the same sound, are said to be in *unison.* The relation between a note and its octave is, next after that of the unison, the most perfect in nature; and when the two notes are sounded at the same time, they almost entirely unite. Chords are produced by frequent *coincidences of vibration,* while in discords such coincidences are more rare. Thus, in the unison, the vibrations are exactly coincident; in the octave, the two coincide at the end of every vibration of the longer string, the shorter meanwhile performing just two vibrations; but in the second, the vibrations of the two

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sounds? How does music become a branch of mathematical science? Example in a musical string. Define melody, chords, harmony, unison. How are chords produced? How discords?

strings coincide only after eight of one string and nine of the other, and the result is a harsh discord.

128. When an impulse is given to air contained in an open tube, the vibrations coalesce, and are propagated farther than when similar impulses are made on the open air. Hence the increase of sound effected by horns and trumpets, and especially by the speaking trumpet. Alexander the Great is said to have had a horn, by means of which he could give orders to his whole army at once. *Acoustic Tubes* are employed for communicating between different parts of a large establishment, as a hotel, or manufactory, by the aid of which, whatever is spoken at one extremity is heard distinctly at the other, however remote. They are usually made of tin, being trumpet-shaped at each end. They act on the same principle as the speaking trumpet. The *Stethoscope* is an instrument used by physicians, to detect and examine diseases of the lungs and the heart. It consists of a small pipe of wood or ivory with funnel-shaped mouths, one of which is applied firmly to the part affected and the other to the ear. By this means the processes that are going on in the organs of respiration, and in the large blood-vessels about the heart, may be distinctly heard.

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128. Explain the effect of horns and trumpets. Use of Acoustic Tubes. How made? Explain the construction and use of the Stethoscope.

CHAPTER VII.

ELECTRICITY.*

DEFINITIONS—CONDUCTORS AND NON-CONDUCTORS—ATTRACTIONS AND REPULSIONS—ELECTRICAL MACHINES—LEYDEN JAR—ELECTRICAL LIGHT AND HEAT—THUNDER STORMS—LIGHTNING RODS—EFFECTS OF ELECTRICITY ON ANIMALS.

129. More than two thousand years ago, Theophrastus, a Greek naturalist, wrote of a substance we call amber, which, when rubbed, has the property of attracting light bodies. The Greek name of amber was *electron*, (ηλεκτρον,) whence the science was denominated ELECTRICITY. The inconsiderable experiment mentioned by Theophrastus, was nearly all that the ancients knew of this mysterious agent; but for two or three centuries past, new properties have been successively discovered, and new modes of accumulating it devised, until it has become one of the most important and interesting departments of natural science. It is common to call this power, whatever it is, the electric fluid, although it is of too subtile a nature for us to show it, as we do air, and prove that it possesses the properties of ordinary matter. But as it is more like an elastic fluid of extreme rarity, than like any thing else we are acquainted with, it is convenient to denominate it a fluid, although we know very little of its nature.

130. Some bodies permit the electric fluid to pass freely through them, and are hence called *conductors;* others hardly permit it to pass through them at all, and

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* The experiments in this chapter are so simple, and require so little apparatus, that it is hoped the learner will generally have the advantage of witnessing them, which will add much more than mere description to his improvement and gratification.

129. Explain the name electricity. What did the ancients know of this science? Its progress within two hundred years? Why is electricity called a fluid?

130. Define conductors and non-conductors. Give examples of

are therefore called *non-conductors.* Metals are the best conductors; next, water and all moist substances; and next, the bodies of animals. Glass, resinous substances, as amber, varnish, and sealing wax; air, silk, wool, cotton, hair, and feathers, are *non-conductors.* Wood, stones, and earth, hold an intermediate place: they are bad conductors when dry, but much better when moist; and air itself has its non-conducting power greatly impaired by the presence of moisture. Electricity is *excited* by friction. If I rub the side of a dry glass tumbler, or a lamp chimney, on my coat sleeve, the electricity excited will manifest itself by attracting such light substances as bits of paper, cotton, or down. A stick of sealing-wax, when rubbed, exhibits similar effects. When an electrified body is supported by non-conductors so that its electricity cannot escape, it is said to be *insulated.* Thus, a lock of cotton suspended by a silk thread is insulated, because if electricity be imparted to the cotton, it remains, since it cannot make its escape either through the thread, or through the air, both being non-conductors. A brass ball supported by a pillar of glass is insulated; but when supported on a pillar of iron or any other metal, it is *uninsulated,* since the electricity does not remain in the ball, but readily makes its escape through the metallic support. By knowing how to avail ourselves of the conducting properties of some substances, and the non-conducting properties of other substances, we can either confine, or convey off the electric fluid at pleasure.

131. There are a number of different classes of phenomena which electricity exhibits; as attraction and repulsion—heat and light—shocks of the animal system—and mechanical violence. These will suc-

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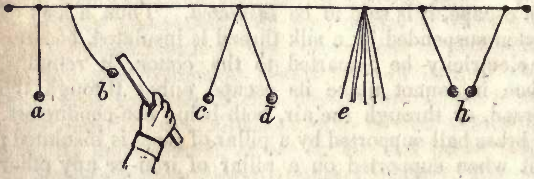
each. How is conducting power affected by moisture? How is electricity excited? When is a body insulated? Give examples of insulation.

cessively claim our attention; but as the properties of electricity were first discovered by experiment, so it is by experiments, chiefly, that they are still to be learned. We will therefore describe, first, a few such experiments as every one may perform for himself, and afterwards such as require the aid of an electrical machine.

SEC. 1. *Of Electrical Attractions and Repulsions.*

132. For a few simple experiments, we will stretch a wire horizontally between the opposite walls of a room, or between any two convenient points, as represented in figure 57. This will afford a convenient support for *electroscopes*, as those contrivances are called, which are used for detecting the presence and examining the properties of electricity. A downy feather, a lock of cotton, or pith-balls,* are severally convenient substances for electroscopes. To one of these, say a pith-ball, we will tie a fine linen thread, about nine inches long, and suspend it from the wire, as at *a*. By slightly wetting the thumb and finger and drawing the

Fig. 57.



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* The pith of elder, of corn stalk, or of dry stalks of the artichoke, is suitable for this purpose.

131. What different classes of phenomena does electricity exhibit? Use of experiments.

132. Describe the apparatus in Fig. 57. How is the tube excited?

thread through them, it becomes a good conductor, and the electroscope is therefore uninsulated. We will now take a thick glass tube and rub it with a piece of silk, (or a dry silk handkerchief,) by which means the tube will be excited, and on approaching it towards the electroscope, the pith-ball will be attracted towards it, as at *b*, and may be led in any direction by shifting the position of the tube; or if the tube be brought nearer, the ball will stick fast to it. We will next suspend two other balls, *c* and *d*, by silk threads, in which case they will be insulated. If we now approach the excited tube, the balls will first be attracted to it, but as soon as they touch it, they will fly off, and the tube when again brought towards them will no longer attract but will repel them, and they will mutually repel each other as in the figure; and if the lock of threads, *e*, be electrified, they will also repel each other. A stick of sealing-wax excited and applied to the electroscopes will produce similar effects. But if we first electrify the ball with glass, and then bring near it the sealing-wax, previously excited, it will not repel the ball, as the excited tube does, but will first attract it as though it were unelectrified, and then repel it; and now the excited glass tube will attract it. Hence it appears that the glass and the sealing-wax, when excited, produce opposite effects: what one attracts the other repels. Each repels its own, but attracts the opposite. Glass repels a body electrified by itself, but attracts a body electrified by sealing-wax; and sealing-wax repels a body electrified by itself, but attracts a body electrified by glass. In the figure, *h* represents two balls differently electrified, one by glass and the other by sealing-wax, and therefore attracting each other. This fact has led to the conclusion, that

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Effect when applied to the uninsulated ball—to the insulated balls—to the threads. Describe the effects when sealing-wax is used—when the balls are differently electrified. What are the two kinds of electricity?

there are *two kinds of electricity;* one excited by glass and a number of bodies of the same class, called the *vitreous* electricity, and the other excited by sealing-wax and other bodies equally numerous, of the same class with it, called the *resinous* electricity. Vitreous electricity is sometimes called *positive,* and resinous electricity *negative.*

133. The foregoing cases of electrical attractions and repulsions constitute important laws of electrical action, and are to be treasured up in the memory in the following propositions:

First. An electrified body *attracts* all unelectrified matter.

Secondly. Bodies electrified similarly, that is, both positively or both negatively, *repel* each other.

Thirdly. Bodies electrified differently, that is, one positively and the other negatively, *attract* each other.

Fourthly. The force of attraction or repulsion is *inversely as the square of the distance;* that is, when two balls are electrified, the one positively and the other negatively, the force of attraction increases rapidly as they draw near to each other, being four times as great when twice as near, and a hundred times as great when ten times as near. Repulsion follows the same law; that is, when two balls are similarly electrified, it requires four times the force to bring them twice as near to each other, and a hundred times the force to bring them ten times as near as before.

SEC. 2. *Of Electrical Apparatus.*

134. Electrical machines afford the means of accumulating the electric fluid, so as to render its effects far more striking and powerful than they appear in the simple experiments already recited. The *cylinder*

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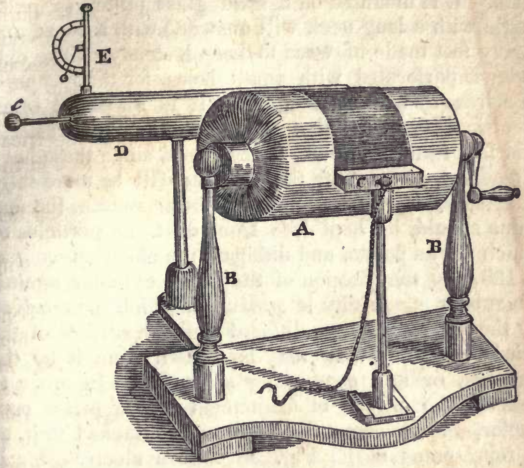
133. State the four laws of electrical attraction and repulsion

machine is represented in Fig. 58. Its principal parts are the cylinder, the frame, the rubber, and the prime conductor. The *cylinder* (A) is of glass, from eight to twelve inches in diameter, and from twelve to eighteen inches long. The *frame* (B B) is made of hard wood, dried and varnished. The rubber (C) consists of a leathern cushion, stuffed with hair like the pad of a saddle. This is covered with a black silk cloth, having a flap, which extends from the cushion over the top of the cylinder to the distance of an inch from the points of the prime conductor, to be mentioned presently. The rubber is coated with an *amalgam*, composed of quicksilver, zinc, and tin, which preparation has been found by experience to produce

Fig. 58.



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134. Describe the electrical machine—the cylinder—the frame—the rubber—the amalgam—the prime conductor.

a high degree of electrical excitement, when subjected to the friction of glass. The *prime conductor* (D) is usually a hollow cylinder of brass or tin, with rounded ends. It is mounted on a solid glass pillar, (a junk-bottle with a long neck will answer,) with a broad and heavy foot made of wood to keep it steady. The cylinder is perforated with small holes, for the reception of wires (c) with brass knobs. It is important in an electrical machine, that the work should be smooth and free from points and sharp edges, since these have a tendency to dissipate the fluid, as will be more fully understood hereafter. For a similar reason, the machine should be kept free from dust, the particles of which act as points, and dissipate the electricity.

135. By the friction of the glass cylinder against the rubber, electricity is produced, which is received by the points, and thus diffused over the surface of the prime conductor, and may be drawn from it by the knuckle, or any conducting substance. In order to indicate the degree of excitement in the prime conductor, the *Quadrant Electrometer* is attached to it, as is represented at E, Fig. 58. This electrometer is formed of a semicircle, usually of ivory, divided into degrees and minutes, from 0 to 180. The index consists of a straw, moving on the center of the disk, and carrying at the other extremity a small pith-ball. The perpendicular support is a pillar of brass, or some conducting substance. When this instrument is in a perpendicular position, and not electrified, the index hangs by the side of the pillar, perpendicularly to the horizon; but when the prime conductor is electrified, it imparts the same kind of electricity to the index, repels it, and causes it to rise on the scale towards an angle of 90 degrees, which point indicates a full charge.

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135. How is the electricity produced? Describe the quadrant electrometer, and show how it indicates the degree of the charge.

136. Let us now try a few experiments. If we turn the machine one or two rounds, the prime conductor will be charged, and the quadrant electrometer will remain fixed at 90 degrees. We will first examine the conducting powers of different bodies. A glass tube held in the hand and applied to the prime conductor will not cause the index of the electrometer to fall, because glass is a non-conductor of electricity; but an iron rod thus applied, will cause the index to fall instantly, iron being a good conductor, and permitting the fluid readily to escape first to my hand, and through my person to the floor, and finally to the earth. On applying a knuckle to the prime conductor, we find, in the same manner, that the animal system is a good conductor, as the fluid is instantly discharged and the index falls. On the other hand, a piece of sealing-wax will not affect the index, and is therefore a non-conductor. So, if we hold a lock of cotton by a silk thread it will scarcely affect the electrometer, while if held by a linen thread, the fluid will be drawn off and the index will fall. It is very useful for the learner to try in this way the conducting powers of a great variety of bodies. Some he will find to affect the electrometer very little, and he will thus know them to be non-conductors; others will instantly cause it to fall, and are known as good conductors. Others will cause the index to descend gradually, and are of course imperfect conductors. These last, on being moistened with the breath or wet with water, will indicate an increase of conducting power. A *long* stick of wood, as a broom-handle, will be found to conduct with less power than a *short* stick of the same, and a large thread will conduct better than a small one.

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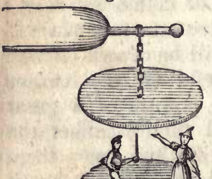
136. Experiments on the conducting powers of bodies—glass—iron—the knuckle—sealing-wax—a silk thread. State the effect of each of these. What is the effect on conducting power produced by moisture—by increasing the length or size of a bad conductor?

Thus all the different circumstances affecting the conducting power, may be ascertained; and upon the knowledge of these relative powers, depends the art of managing the electric fluid, whether in the form of common electricity or in that of lightning.

137. The laws of *attraction* and *repulsion* may be verified by the aid of an electrical machine, much more strikingly than by the simple apparatus mentioned in Articles 132 and 133. If we hang a lock of hair to the prime conductor, on turning the machine the hairs will recede violently from each other, because bodies similarly electrified repel each other. By placing light bodies, as paper images, locks of cotton, or light feathers, between one plate connected with the prime conductor and another which is uninsulated, as is represented in figure 59, (the upper plate being hung to the prime conductor,) the *electrical dance* may be performed. The images will first be attracted to the upper plate, but instantly imbibing the same electricity, they will be repelled by the upper and attracted by the lower plate; on descending to the latter, they will give up their charge and return again to the upper plate to repeat the process, thus performing a kind of dance, which when performed by little images of men and women, is often very amusing. Most electrical machines are furnished with a variety of apparatus for illustrating the principles of electrical attractions and repulsions, such as a chime of bells, the electrical horse-race, the electrical wind-mill, and

Fig. 59.



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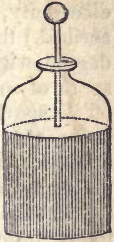
137. Effect when a lock of hair is hung to the prime conductor? How is the electrical dance performed?

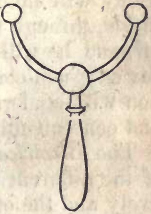
the like; but these must be seen in order to be fully understood, and therefore their exhibition is left to the instructor.

Fig. 60.



138. The *Leyden Jar* is a piece of apparatus used for accumulating a large quantity of electricity. It consists of a glass jar coated on both sides with tin foil, except a space on the upper end, within two or three inches of the top, which is either left bare, or is covered with a coating of varnish, or a thin layer of sealing wax. To the mouth of the jar is fitted a cover of hard baked wood, through the center of which passes a perpendicular wire, terminating above in a knob, and below in a fine chain that rests on the bottom of the jar. On presenting the knob of the jar near the prime conductor of an electrical machine, while the latter is in operation, a series of sparks pass between the conductor and the jar, which will gradually become more and more feeble, until they cease altogether. The jar is then said to be *charged*. If we now take the *discharging rod*, (which is a bent wire, armed at both ends with knobs, and insulated by a glass handle, as in figure 61,) and apply one of the knobs to the outer coating and bring the other to the knob of the jar, a flash of intense brightness, accompanied by a loud report, immediately ensues. If, instead of the discharging rod, we apply one hand to the outside of the charged jar, and bring a knuckle of the other hand to the knob of the jar, a sudden and surprising *shock* is felt, convul-

Fig. 61.



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138. Define the Leyden Jar—describe it—how is it charged? How discharged? How is the shock taken?

sing the arms, and when sufficiently powerful, passing through the breast.

139. The outside and the inside of a Leyden Jar are always found in opposite states; that is, if to the knob connected with the inside we have imparted positive electricity, (as in the mode of charging already described,) then the outside will be electrified in the same degree with negative or resinous electricity. Every spark of one sort of fluid that enters into the jar, drives off a spark of the same kind from the outside, and leaves that in the opposite state. And if the jar is insulated, (as when it stands on a glass support,) so that the electricity cannot pass from the outer coating, then it will take no charge. We may charge a jar negatively instead of positively, by grasping hold of the knob and presenting the outside to the prime conductor. The positive electricity that enters the outer coating, drives off an equal quantity of the same kind from the inside, which escapes through the body of the operator and leaves the inner coating negative. When the jar is thus charged, we must be careful to set it down on a *glass* support before withdrawing the hand; for if we place it on the table, which is a conductor, the electricity will immediately rush from the outside to the inside, through the table, floor, and body of the operator, and he will receive a shock. But if he sets the jar on a non-conducting support, no such communication will be formed between the two sides of the jar, and consequently it will not discharge itself.

The *Electrical Spider* forms a pleasing illustration of the different states of two jars, one charged positively and the other negatively. It is contrived as follows: Take a bit of cork and form a small ball of the size of a pea, for the body of the spider. With a needle, pass a fine black thread backward and for-

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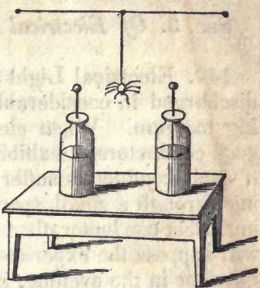
139. In what state are the two sides of a charged jar? How may we charge a jar negatively? Why is it necessary to set it down on an

ward through the sides of the cork, letting the threads project from it half or three fourths of an inch on the opposite sides, to form the legs. Now suspend it from the center of the body by a fine silk thread, between two jars, one charged positively and the other negatively, and placed on a table, as is represented in figure 62. The spider will first be attracted to the knob of the nearest jar, will imbibe the same electricity, be repelled, and attracted to the knob of the other jar, from which again it will be repelled, and so will continue to vibrate back and forth between the two jars, until it has restored the equilibrium between them by slowly conveying to the inside of each jar the electricity of the inner coating of the other.

Fig. 62.



Pointed conductors have a remarkable power of drawing off and dissipating the electric fluid when it has accumulated. If we apply one hand to the outer coating of a charged jar, and with the other bring a needle towards the knob, it will silently draw off all the charge, without giving any shock. And if, while we are charging a jar with the machine, we direct a pointed wire or a needle towards the machine, even at a much greater distance from it than the knob of the jar, the fluid will

Fig. 63.

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insulated support? Describe the electrical spider. Why does it vibrate from one jar to the other? Effect of points.

pass into the needle in preference to the jar. All apparatus, therefore, for confining electricity, requires to be free from sharp lines and points, and to terminate in round smooth surfaces.

SEC. 3. *Of Electrical Light and Heat.*

140. Electrical Light appears whenever the fluid is discharged in considerable quantities through a resisting medium. When electricity flows freely through good conductors, it exhibits neither light nor heat; but if such conductors suffer any interruption, as in passing through a small space of air, or even through an imperfect conductor, then light becomes manifest. We will suppose the experiment to be performed in a dark room, or in the evening, in a room very feebly lighted. A glass tube, rubbed with black silk, coated with a little electrical amalgam, will afford numerous sparks, with a slight crackling noise. A chain, hung to the prime conductor of a machine, will show a bright spark at every link. If we attach one end of the chain to the prime conductor, and hold the other end suspended by a glass tube, brushes or pencils of light will issue from various points along the chain. The spark seen in discharging the Leyden Jar, as in Article 138, is very intense and dazzling.

Fig. 64.

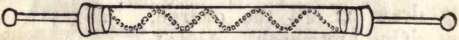

Figure 64 represents a glass cylinder, armed at each end with brass balls, and wound round, spirally, with a narrow strip of tin foil. At short intervals, small portions of the tin foil are cut out, so as to interrupt

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140. When does electrical light appear? When does electricity exhibit neither light nor heat? Experiment with a glass tube—a chain—a spiral tube? How may illuminated words be made to appear?

the circuit. Whenever a spark is passed through this apparatus, it appears beautifully luminous at every interruption in the tin foil. Words or figures of any kind may be very finely exhibited by coating a plate of glass with a strip of tin foil in a zigzag line, from one corner to the opposite corner, diagonally. Then with the point of a knife, small portions of the tin foil are nicked out in such a manner that the spaces thus left bare shall together constitute some word, as WASHINGTON. The spark, in passing through the tin foil, will meet with resistance at all the places where the metal has been removed, and will there exhibit a bright light. Thus an illuminated word will appear at every spark received from the machine. If the machine is not sufficiently powerful to afford a spark strong enough to overcome the resistance occasioned by so many non-conducting spaces, then the illuminated word may be made to appear with great splendor, by making the plate form a part of the circuit between the inside and the outside of a charged Leyden Jar.

141. By means of the *Battery*, far more brilliant experiments may be performed than with a single jar. The Battery consists of a number of jars, twelve, for instance, so combined that the whole may be either charged or discharged at once. Large Leyden Jars, placed side by side in a box, standing on tin foil, which forms a conducting communication between the outer coatings, while the inner coatings are also in communication by a system of wires and knobs, answer the same purpose as a single jar of enormous size, and are far more convenient. When the battery is charged, and a chain is made to form a part of the circuit between the outside and inside, on discharging it, the whole chain is most brilliantly illuminated. Rough

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141. The Battery—of what does it consist? Describe it. How is a chain illuminated by the battery? Great power of some batteries.

lightning rods sometimes present a similar appearance when struck during a thunder storm. Batteries are sometimes made of sufficient power to kill small animals, and even men.

142. *Heat,* as well as light, attends the electric spark, although, except when the discharge is very powerful, as in the case of the battery, or of lightning, it is but feeble, sufficient to set on fire only the most inflammable substances. Alcohol and ether, two very inflammable liquids, may be fired by the spark, a candle may be lighted, and gunpowder exploded. It is, however, difficult to set powder on fire by electricity, unless the spark is very strong.

143. The electric spark passes much more easily through *rarefied* air, than through air in its ordinary state. Thus, a spark which would not strike through the air more than four or five inches, will pass through an exhausted glass tube, four feet or more in length, filling all the interior with a soft and flickering light, somewhat resembling the Aurora Borealis. Hence, that phenomenon has been ascribed by some to electricity, though this is probably not its true explanation.

144. In *Thunder Storms,* we see electricity exhibited in a state of accumulation far beyond what we can create by our machines, and producing effects proportionally more energetic. A cloud presents a conductor insulated by the surrounding air, in which, in hot weather, electricity collects and accumulates as it would upon a prime conductor of immense size. By sending up a kite armed with points, electricity may be drawn from such clouds, and made to descend by a wire wound round the string of the kite. We

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142. Does heat attend electricity? Give examples of bodies fired by it.

143. How does the spark pass through rarefied air? Explain the appearance of the Auroral tube.

144. How is electricity exhibited in thunder storms? Analogy between a cloud and a prime conductor. How may lightning be drawn

may easily direct it upon a prime conductor, or charge a Leyden Jar with it, and examine its properties as we should do in the case of ordinary electricity. By such experiments, it is found that the clouds are sometimes positively and sometimes negatively electrified. In thunder storms, the lightning is usually nothing more than the electric spark passing from one cloud to another differently electrified, as it passes between the outer and inner coating of the Leyden Jar. The flash appears in the form of a line, because it passes so swiftly, just as a stick, lighted at the end and whirled in the air, forms a circle of light. The motion of the electric fluid is, to all appearance, instantaneous. Thunder is the report occasioned by the rushing together of the air, after it has been divided by the passage of the lightning. The cracking of a whip, as already mentioned, is ascribed to the same cause. The lash divides the air into two parts, which forcibly rush together and occasion the sound. When a thunder-clap is very near us, the report follows the flash almost instantly, and such claps are dangerous. In all cases, the lightning and the thunder actually occur at the same moment, but when the discharge is at some distance from us, the report is not heard till some time after the flash; for the light reaches the eye instantaneously, but the sound travels with comparative slowness, moving only about a mile in five seconds. We may, therefore, always know nearly how distant a thunder cloud is, by counting the number of seconds between the flash and the report, and allowing the fifth of a mile (or, more accurately, 1,130 feet) to a second. (See Art. 124.)

145. Sometimes lightning, instead of passing from

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from the clouds? How is the flash produced in thunder storms? Why does it leave a bright line? What is thunder? How produced? Why are the flash and the report sometimes together and sometimes separate?

cloud to cloud, discharges itself into the earth, and then strikes objects that come in its route, as houses, trees, animals, and sometimes man. As electricity always selects, in its passage, the best conductors, Dr. Franklin first suggested the idea of protecting our dwellings by means of *Lightning Rods*. If these are properly constructed, the lightning will always take its passage through them in preference to any part of the house, and thus they will afford complete protection to the family. Sharp metallic points were observed by Dr. Franklin to have great power to discharge electricity from either a prime conductor or a Leyden Jar, and this suggested their use in lightning-rods. Metals, also, being the best conductors of electricity, would obviously afford the most proper material for the body of the rod.

There are three or four conditions in the construction and application of a lightning-rod, which are essential to insure complete protection. The rod must not be less than three-fourths of an inch in diameter—it must be continuous throughout, and not interrupted by loose joints—it must terminate above in one or more sharp points of some metal, as silver, gold, or platina, not liable to rust—it must enter the ground to the depth of permanent moisture, which will be different in different soils, but usually not less than six feet. A rod thus constructed will generally protect a space every way equal to twice its height above the ridge of the house. Thus, if it rises fifteen feet above the ridge, it will protect a space every way from it of thirty feet. It is usually best to apply the rod to the chimney of the house; or, if there are several chimneys, it is best to select one as central as possible. The kitchen

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145. What happens when lightning strikes to the earth? Lightning-rods—influence of points and conductors—power of metals—size of the rod—to be continuous—how terminated above and below? How much space will a rod protect? How applied to a house? What is

chimney, being usually the only one in which fires are maintained during the season of thunder storms, requires to be specially protected, since a column of smoke rising from a chimney is apt to determine the course of the lightning in that direction. If, therefore, the lightning-rod is attached to some other chimney of the house, either a branch should proceed from it up the kitchen chimney, or this should have a separate rod. As lightning, in its passage from a cloud to the earth, selects tall pointed objects, it often strikes trees, and it is, therefore, never safe to take shelter under trees during a thunder storm. Persons struck down by lightning are sometimes recovered by dashing on repeated buckets of water.

SEC. 4. *Of the Effects of Electricity on Animals.*

146. When we apply a knuckle to the prime conductor of an electrical machine, and receive the spark, a sharp and somewhat painful sensation is felt. If we receive the charge of a Leyden Jar, a *shock* is experienced which is more or less severe, according to the size and power of the jar. A battery gives a shock still more severe, and it may be even dangerous. Lightning, it is well known, sometimes prostrates and kills men and animals. A convenient method of taking the *shock*, is to charge a

Fig. 65.

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said of the kitchen chimney? May we take shelter under trees? How to restore people struck by lightning?

146. Sensation to the knuckle—effects of a jar—of a battery. What is a convenient mode of taking the shock? Sensations produced by

quart jar, place it on a table, and grasping in each hand a metallic rod, apply one rod to the outside of the jar, and touch the other to the knob connected with the inside. If the charge is feeble, it will be felt only in the arms; if it is stronger, it will be felt in the breast; and it may be sufficiently powerful to convulse the whole frame. Any number of persons may, by taking hold of hands, all receive the shock at the same instant. The first must touch the outside, and the last the knob of the jar. Whole regiments have been electrified at once in this way.

147. Electricity is sometimes employed *medicinally*, and is thought to afford relief in various diseases. It may be applied either to the whole system at once, or to any individual part, by making that part form a portion of the communication between the inside and the outside of a jar. Or the fluid may be taken in a milder form by means of the *Electrical Stool*. This is a small stool, resting on glass feet. The patient stands or sits on the stool, and holds a chain connected with the prime conductor, while the machine is turned. This produces an agreeable excitement over the whole system: the hair stands on end; sparks may be taken from all parts of the person, as from a prime conductor; and the patient may communicate a slight

Fig. 66.

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a feeble charge—by a strong—by a powerful charge? How may any number of persons be electrified at once?

147. How is electricity employed medicinally? How by means of the electrical stool?

shock to any one that comes near him, or may set on fire ether and other inflammable substances, by merely touching them with a rod, or pointing toward them.

148. Several *fishes* have remarkable electrical powers. Such are the Torpedo, the Gymnotus, and the Silurus. The Gymnotus, or Surinam eel, is found in the rivers of South America. Its ordinary length is from three to four feet; but it is said to be sometimes twenty feet long, and to give a shock that is instantly fatal. Thus, it paralyzes fishes, which serve as its food, and in the same manner it disables its enemies and escapes from them. By successive efforts, electrical fishes exhaust themselves. In South America, the natives have a method of taking them, by driving wild horses into a lake where they abound. Some of the eels are very large, and capable of giving shocks so powerful as to disable the horses; but the eels themselves are so much exhausted by the process, as to be easily taken.

CHAPTER VIII.

MAGNETISM.

DEFINITIONS—ATTRACTIVE PROPERTIES—DIRECTIVE PROPERTIES —VARIATION OF THE NEEDLE—DIP—MODES OF MAKING MAGNETS.

149. AMONG the ores of iron, there is found an ore of a peculiar kind, which has the power of attracting iron filings, and other forms of metallic iron, and is called the *loadstone*. This power can be imparted to bars of steel, which are denominated *magnets*. The unknown power which produces the peculiar effects of the magnet, is called *magnetism*. This name is

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148. What of electrical fishes? Give an account of the Gymnotus. How do the natives take electrical fishes in South America?

149. What is the loadstone, and magnets? Define *Magnetism*—

also applied, as at the head of this chapter, to that branch of Natural Philosophy which treats of the magnet. *Magnetic bars* are thick plates of iron or steel, commonly about six inches long. If a magnetic bar be placed among iron filings, they will arrange themselves around a point at each end, forming tufts, as is shown in figure 67. These two points are called the *poles*, and the straight line that joins them, the *axis* of the magnet. If we suspend, by a fine thread, a small needle, and approach toward it either pole of a metallic bar, the needle will rush toward it and attach itself strongly to the pole. By rubbing the needle on one of the poles of the magnet it will itself imbibe the same power of attracting iron, and become a magnet, having its poles. If we now bring first one pole of the magnetic bar toward the needle, and then the other pole, we shall find that one attracts, and the other repels the needle. Figure 68 represents two large sewing needles, magnetized, and suspended by fine threads. On approaching the north pole of a magnetic bar to the north poles of the needles, they are forcibly repelled; but on applying the south pole of a bar, as in figure 69, the north poles of the needles are attracted toward it.

Fig. 67.

Fig. 68.

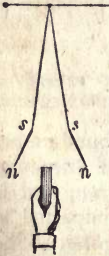
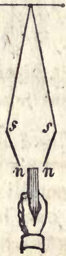


Fig. 69.



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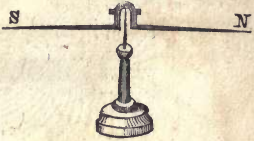
two senses in which the word is used. What are magnetic bars? What are the poles—the axis? How may a needle be magnetized? How are its properties changed by this process?

150. Let us suppose that the long needle represented in figure 70, has been rubbed on a magnet, so as to imbibe its properties, or to become *magnetized;* then, on balancing it on a pivot, it will of its own accord place itself in nearly a north and south line, and return forcibly to this position when drawn aside from it. This property is called the *directive,* while the other is called the *attractive,* property of the magnet. That end which points northward, is called the *North Pole* of the magnet, and that end which points southward, is called the *South Pole.* Every magnet has these two poles, whatever may be its size or shape. A magnetic bar has usually a mark across one end, to denote that it is the north pole, the other, of course, being the south pole. If the north pole of a bar be brought toward the north pole, N, (Fig. 70,) of the needle, it will repel it, and the more forcibly in proportion as we bring it nearer to N. On the contrary, if the north pole of the bar be brought toward the south pole S of the needle, it will attract it. Also, if we present the south pole of the bar first to one pole of the needle, and then to the other, we shall find that the bar will repel the pole of the same name with its own, and attract its opposite. These facts are expressed by the proposition that *similar poles repel, and opposite poles attract each other.* When a magnetic bar is laid on a sheet of paper, and iron filings are

Fig. 70.



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150. Explain the *directive* property. Which is the north and which the south pole? How is the north pole distinguished? Effect when the north pole of the bar is brought near the north pole of the needle—when the north pole is brought toward the south pole? State the general fact. What takes place when a magnetic bar is placed among iron filings?

sprinkled on it, they will arrange themselves in curves around it, as in figure 71.

Fig. 71.

151. The magnetic needle, when freely suspended, seldom points directly to the pole of the earth, but its deviation from that pole, either east or west, is called the *variation* of the needle. A line drawn on the surface of the earth, due north and south, is called a *meridian line*. The needle usually makes a greater or less angle with this line. Its direction is called the *magnetic meridian*, and the place on the earth to which it points, is called the *magnetic pole*. The earth has two magnetic poles, one in the northern, the other in the southern hemisphere. The north magnetic pole is in the part of North America lying north of Hudson's and west of Baffin's Bay, in latitude 70°. The variation of the needle is different in different countries. In Europe, the needle points nearly N. W. and S. E.; while in the United States it deviates nowhere but a few degrees from north and south; and along a certain series of places, passing through Western New York and Pennsylvania, the variation is nothing; that is, the needle points directly north and south. At the same place, moreover, the variation of the needle is different at different periods. For a long series of years, the needle will slowly approach the

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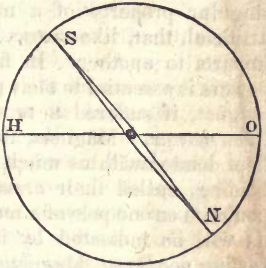
151. What is meant by the variation of the needle? What is a meridian line?—the magnetic meridian? Situation of the north magnetic pole? How is the variation of the needle in Europe? How in the United States? Where does the line of no variation run? How

North pole, come within a certain distance of it, and then turn about and again slowly recede from it. At Yale College, the variation in 1843, was 6½ degrees West, and is increasing at the rate of 4½ minutes a year.

152. A needle first balanced on its center of gravity, and then magnetized, no longer retains its level, but it points below the horizon, making an angle with it, called the *Dip of the needle*.

Fig. 72.



The dipping needle is shown in figure 72, adapted to a graduated circle in order to indicate the amount of the depression, and is sometimes fitted with screws and a level to adjust it for observation. The dip of the needle varies very much in different parts of the earth, being in general least in the equatorial, and greatest in the polar regions. At Yale College, it is about 73 degrees, being greater than is exhibited in the figure.

153. The directive property of the needle has two most interesting and important practical applications, in surveying and navigation. The compass needle, in order to keep it at a horizontal level, and prevent its dipping, has a counterpoise on one side, which exactly balances the tendency to point downward. By the aid of this little instrument, lands are measured, and boundaries determined; the traveller finds his way

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does the variation change at any given place? How is it at New Haven?

152. What is the *Dip* of the needle? Describe figure 72. Where is the dip of the needle greatest? Where least? Its amount at Yale College?

153. What are the two leading applications of the needle? How is the compass needle kept from dipping? To what uses is it applied?

through unexplored forests and deserts; and mariners guide their ships through darkness and tempests, and across pathless oceans.

154. There are various methods of *making compass needles*, or artificial magnets. Soft iron readily receives magnetism, but as readily loses it; hard steel receives it more slowly, but retains it permanently. It is a singular property of a magnet, whether natural or artificial, that, like virtue, it loses nothing by what it imparts to another. In fact, such an exercise of its powers is essential to their preservation. The strongest magnet, if suffered to remain unemployed, gradually loses power. Magnets, therefore, and loadstones, are kept loaded with as much iron as they are capable of holding, called their *armature*. If we simply rub a penknife on one pole of a magnet, we render it magnetic, as will be indicated by its taking up iron filings or sewing needles. Magnetism is most readily imparted by a bar, when both its poles are made to act together. This is done by giving the bar the form of a horse-shoe, as in figure 73. To magnetize a needle, we lay it flat on a table, and place the two poles of the horse-shoe magnet near the middle, and rub it on the needle, backward and forward, first toward one end and then toward the other, taking care to pass over each half of it an equal number of times. The needle may then be turned over, and the same process performed on the other side, when it will be found strongly and permanently magnetized.

Fig. 73.

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154. How is the compass needle made? What is said of soft iron and hard steel? How is the strength of the magnet affected by action or inaction? What is the armature? How to magnetize a penknife. Why is a bar bent into the horse-shoe form? How to magnetize a needle with it.

CHAPTER IX.

OPTICS.

DEFINITIONS—REFLEXION AND REFRACTION—COLORS—VISION—MICROSCOPES AND TELESCOPES.

155. OPTICS *is that branch of Natural Philosophy which treats of Light.* Light proceeds from the sun, a lamp, and all other luminous bodies, in every direction, in straight lines, called *rays.* If it consists of matter, its particles are so small as to be incapable of being weighed or measured, many millions being required to make a single grain. Some bodies, as air and glass, readily permit light to pass through them, and are called *transparent;* others, as plates of metal, do not permit us to see through them, and are called *opake.* Any substance through which light passes, is called a *Medium.* Light moves with the astonishing velocity of 192,500 miles in a second. It would cross the Atlantic Ocean in the sixty-fourth part of a second, and in the eighth part of a second, would go round the earth. When light strikes upon bodies, some portion of it enters the body, or is *absorbed,* and more or less of it is thrown back, and is said to be *reflected;* when it passes through transparent bodies, it is turned out of its direct course, and is said to be *refracted.* The light of the sun consists of seven different colored rays, which, being variously absorbed and reflected by different bodies, constitute all the varieties of *colors.* Light enters the eye, and forming within it pictures of external objects, thus gives the sensation of vision. The knowledge of the properties of light, and the nature of vision, has given rise to the invention of many noble and excellent instruments, which afford

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155. Define Optics—terms rays, transparent, opake, and medium. When is light said to be reflected? When refracted? Of what do the

wonderful aid to the eye, such as the *microscope* and the *telescope*. Let us examine more particularly these interesting and important subjects, under separate heads.

SEC. 1. *Of the Reflexion and Refraction of Light.*

156. When rays of light, on striking upon some body, are turned back into the same medium, they are said to be *reflected*. Smooth polished surfaces, like mirrors and wares of metal, reflect light most freely of any, and hence their brightness. Most objects, however, are seen by reflected light; few shine by their own light. Thus, the whole face of nature owes its brightness and its various colors to the light of the sun by day, and to the light of the moon and stars by night. The rays that come from these distant luminaries, fall first upon the atmosphere, and are so reflected and refracted from that as to light up the whole sky, which, were it not for such a power of scattering the rays of light that fall upon it, would be perfectly black. On account of the transparency of the atmosphere, the greater part of the sun's rays pass through it, and fall upon the surface of the earth, and upon all objects near it. These reflect the light in various directions, and are thus rendered visible by that portion of the light which proceeds from them to the eye.

157. When a ray of light strikes upon a plane surface, the angle which it makes with a perpendicular to that surface, is called the *angle of incidence*, and the angle which it makes with the same perpendicular, when reflected, is called the *angle of reflexion*. *The*

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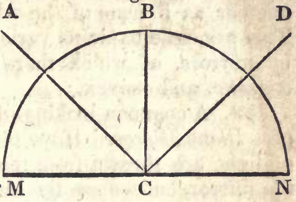
sun's rays consist? To what inventions has the study of Optics given rise?

156. When are rays of light said to be reflected? By what light are most objects seen? Show how the atmosphere and most things on the earth are illuminated.

157. Define the angle of incidence and of reflexion. Equality be-

angle of reflexion is equal to the angle of incidence. Thus, a ray of light, A C, striking upon a plane mirror, M N, at C, will be reflected off into the line C B, making the angle of incidence, M C A, equal to the angle of reflexion, N C D. It is not necessary that the surface on which the light strikes should be a *continued* plane; the small part of a curved surface, on which a ray of light falls, may be considered as a plane, touching the curve at that point, so that the same law of reflexion holds in curved as in plane surfaces. Now the grains of sand on a sandy plain, present surfaces variously inclined to each other, which scatter the rays of the sun in different directions, many of which enter the eye, and make such a region appear very bright; while a smooth surface, like a mirror, or a calm sheet of water, reflects the light that falls on it chiefly in one direction, and hence appears bright only when the eye is so situated as to receive the reflected beam. Thus, the ocean appears much darker than the land, except when the sun shines upon it at such an angle as to throw the reflected beam directly toward the eye, as at a certain hour of the morning or evening, and then the brightness is excessive.

Fig. 74.



158. An object always appears in the direction in which *the last ray of light from it comes to the eye.* Thus, we see the sun below the surface of a smooth lake or river, because every ray of light, being reflected from the water as from a mirror, comes to the eye

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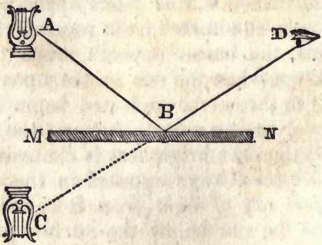
tween these two angles. Explain figure 74. Does the same law hold for curved surfaces? Which appears darkest, the ocean or land, in the light of the sun?

in the direction in which the image appears; and if the light of a star were to change its direction a hundred times in coming through the atmosphere, we should see the star in the direction of the last ray, in the same manner as if none of the other directions had existed. This principle explains various appearances presented by mirrors, of which there are three kinds—plane, concave, and convex.

159. A common looking-glass furnishes an example of a *Plane Mirror*. If we place a lamp before it, rays of light are thrown from the lamp upon every part of the mirror, but we see the lamp by means of those few of the rays only which are reflected to the eye; all the rest are scattered in various quarters, and do not contribute at all to render the object visible to a spectator at any one point, although they would produce, in like manner, a separate image of the lamp wherever they entered an eye so situated as to receive them. Hence, were there a hundred people in the room, each would see a separate image, and each in the direction in which the rays came to his own eye. We will suppose M N to be the looking-glass, having a harp placed

Fig. 75.



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158. In what direction does an object always appear? Example in the sun—in a star. What are the three kinds of mirrors?

159. Explain how the image is formed in a plane mirror. What rays only enable us to see the image? Explain Fig. 75. How far

before it, and the eye of the spectator at D. Of all the rays that strike on the glass, the spectator will see the image by those only which strike the mirror in such a direction, A B, that when reflected from the mirror at the same angle on the other side, they shall enter the eye in the direction B D. The image will appear at C, and *will be just as far behind the mirror as the harp is before it.* This last principle is an important one, and it must always be remembered, that every point in an object placed before a plane mirror, will appear in the image just as far behind the mirror as that point of the object is before it; so that the image will be an exact copy of the object, and just as much inclined to the mirror. We learn, also, the reason why objects appear inverted when we see them reflected from water, as the surface of a river or lake, since the parts of the object most distant from the water, that is, the top of the object, will form the lowest part of the image.

160. If we take a looking-glass and throw an image of the sun on a wall, on turning the mirror round we shall find that the image moves over twice as many degrees as the mirror does. If the image is at first thrown against the wall of a room, horizontally, (in which case the mirror itself would be perpendicular to the horizon,) by turning the mirror through half a right angle, the place of the image would be changed a whole right angle, so as to fall on the ceiling over head. A common table-glass, which turns on two pivots, being placed before a window when the sun is low, will furnish a convenient means of verifying this principle.

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is the image behind the mirror? How far is each point in the image behind the mirror? Why do objects appear inverted when reflected from water?

160. If a mirror be turned, how much faster does the image move than the mirror? State how the experiment is performed.

161. A *Concave Mirror* collects rays of light. If we hold a small concave shaving-glass, for instance, toward the sun, it will collect the whole beam of light that falls upon it into one point, called the *focus.* Figure 76 will give some idea of the manner in which parallel rays strike a concave mirror, converge to a focus, and then diverge. The angle of reflexion is equal to the angle of incidence here, as well as in a plane mirror; but the perpendicular to a curved surface is the radius of the circle of which the curve is a part. Thus, the line C B is the radius of the concave mirror, M N, and, in a circle, every radius is perpendicular to the surface. The sun's rays are parallel to each other, or so nearly so, that they may be considered as parallel; and when rays fall upon the mirror, in the lines A B and E G, they are reflected on the other side of the perpendiculars, meeting in a common focus, F, which point is called the *focus of parallel rays.* Into this point, or a small space around it, a concave mirror will collect a beam

Fig. 76.

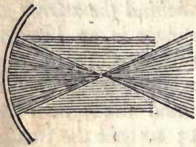
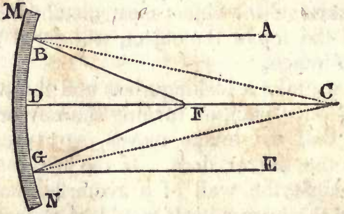


Fig. 77.



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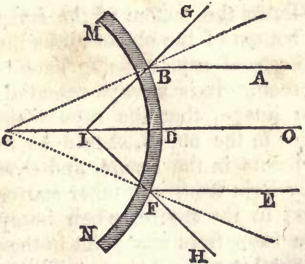
161. What is the office of a concave mirror? Experiment with a shaving-glass. What forms the perpendicular to a concave surface? What is the point called where parallel rays are collected? What is

of the sun, increasing in heat in the same proportion as the illuminated space at F is less than the whole surface of the mirror. In large concave mirrors, the heat at the focus often becomes very powerful, so as not only to set combustibles on fire, but even to melt the most infusible substances. Hence the name focus, which means a *burning* point. If a lamp is placed at F, the rays of light proceeding from it in the lines F G and F B, will strike upon the mirror and be reflected back into the parallels, G E and B A. We shall see hereafter how useful this property of concave mirrors,—to collect parallel rays of light into a focus,—is in the construction of that most noble of instruments, the telescope.

A *Convex Mirror*, on the other hand, *separates* rays of light from each other, still observing the same law, that of making the angle of incidence equal to the angle of reflexion. In figure 78, the parallel rays, A B, O D, E F, are represented as falling on a convex mirror, M N. A B and E F, being reflected to the other sides of the radii, C B and C F, are separated

Fig. 78.



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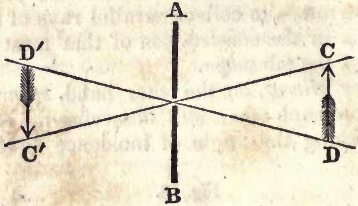
said of the heat at the focus? When a lamp is placed in the focus, how will its light be reflected?

from each other, and form the image at I, which is called the *imaginary focus* of parallel rays, because, at this point, the parallel rays that fall upon the mirror *seem* to meet in a focus behind the mirror, and to diverge again into the lines B G and F H.

162. Whenever the rays of light from the different parts of an object cross each other before forming the image, the image will be *inverted.* It is manifest from figure 79, that the light by which the top of the object is represented forms the bottom of the image, and the light from the bottom of the object forms the top of the image, the two sets of rays crossing each other at the hole in the screen. It is always essential to the distinctness of an image, that the rays which proceed from every point in the object, should be arranged in corresponding points in the image, and should be unaccompanied by light from any other source. Now a screen like that in the figure, when interposed, permits only those rays from any point in the object that are very near together and nearly parallel to each other, to pass through the opening, after which they continue straight forward and form the corresponding point of the image; while rays coming from any other point in the object cannot fall upon the point occupied by the

Fig. 79.



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162. In what case will the image appear inverted? Explain from Fig. 79. What is essential to the distinctness of an image? What rays only does the screen permit to pass?

former pencil, but each finds an appropriate place of its own in the image, and all together make a faithful representation of the object.

163. Concave mirrors form *images* of objects, by collecting the rays from each point of the object into corresponding points in the image, unaccompanied by rays from any other quarter. If the object be nearer than the focus, as in figure 80, a magnified image appears behind the mirror, and in its natural position; but if the object be between the focus and the center, the image is before the mirror, on the other side of the center, larger than the object, and inverted, as it is in figure 81, where the small arrow, A B, situated between the focus and the center of the mirror, is reflected into the image *a b*, inverted and larger than the object. These cases may be verified in a dark room, by placing a lamp at different distances from a concave mirror. As such mirrors form their images in the air without any visible

Fig. 80.

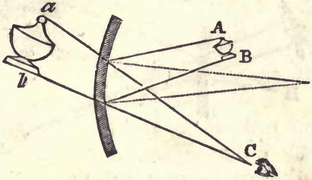
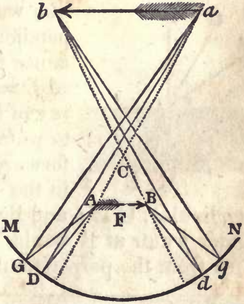


Fig. 81.



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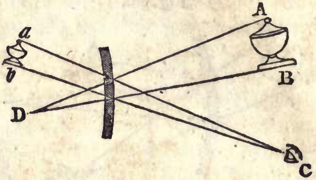
163. How do concave mirrors form images? When the object is nearer the mirror than the focus, how does the image appear? How when it is farther than the focus? How may these cases be

support, they have sometimes been employed by jugglers to produce apparitions of ghostly figures, drawn swords, and the like, which were made to appear in terrific forms, while the apparatus by which they were produced, was entirely concealed from the spectators.

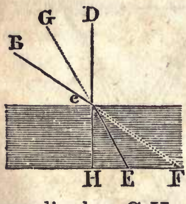
Fig. 82.



A convex mirror gives a diminished image of any object placed before it, representing it in its natural position, and behind the mirror, as in figure 82.

164. *Refraction is the change of direction which light undergoes by passing out of one medium into another.*

Fig. 83.



When light passes out of a rare medium, like air, into a dense medium, like water, it is turned *toward* a perpendicular; when it passes out of a dense into a rare medium, it is turned *from* a perpendicular. When the ray of light, B C, passes out of air into water, it will not proceed straight forward in the line C F, but will go in the line C E, nearer to the perpendicular, C H; and light proceeding from an object under water at E would, on passing into the air at C, turn from the perpendicular into the line C B. Since

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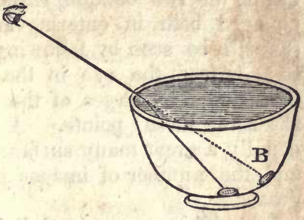
verified? What use is made of concave mirrors by jugglers? How do convex mirrors represent objects?

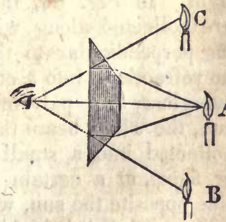
164. Define refraction. How is light reflected by passing out of air into water—out of water into air? Explain Fig. 83. Also, Fig.

Fig. 84.



objects always appear in the direction in which the light finally comes to the eye, the place of an image is changed by its light passing through a refracting medium before it reaches the eye. Fig. 84 represents a bowl with a small coin at the bottom. An eye situated as in the figure, would not see the coin; but, on turning water into the bowl, the coin becomes visible at B, because the light proceeding from the coin is bent toward the eye in passing out of the water. For a similar reason, an oar in water appears bent, the part immersed being elevated by refraction. The bottom of a shallow river appears higher than it really is, and people have been drowned by attempting to ford a river which, from the effect of refraction, appeared less deep than it was.

Fig. 85.



165. The Multiplying Glass shows as many images of an object as there are surfaces, since each surface refracts the light that falls upon it, in a different angle from the others; of course the rays meet the eye in the same number of different directions, and the object appears in the direction of each. The candle at A, Fig. 85, sends rays to each of the three surfaces of the glass. Those which fall on it perpendicularly, pass directly through the

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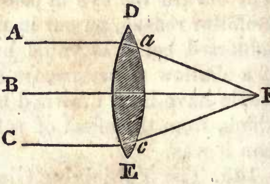
84. Why an oar in water appears bent? How does refraction affect the apparent depth of a river?

165. Describe the multiplying glass, and explain its effects.

glass to the eye, without change of direction, and form one image in its true place at A. But the rays which fall on the two oblique surfaces, have their directions changed both in entering and in leaving the glass, (as will be seen by following the rays in the figure,) so as to meet the eye in the directions of B and C. Consequently, images of the candle are formed, also, at both these points. A multiplying glass has usually a great many surfaces inclined to one another, and the number of images it forms is proportionally great.

166. This property of light—the power of having its direction changed by refraction—is converted to very important and interesting uses by means of LENSES. A lens is exemplified in a common sun-glass, (or even in a spectacle-glass,) and is either convex or concave. Convex lenses, like concave mirrors, *collect* rays of light. In Fig. 86, the parallel rays, A *a* and C *c*, are collected along with the central ray (which being perpendicular to the surfaces of the lens, suffers no refraction) into a common focus in F. If I hold a sun-glass, or a pair of convex spectacles toward the sun, the whole beam that falls upon the glass will be collected into a small space, forming a bright point, or focus, at a certain distance from the lens on the side opposite the sun, where it may be received on a screen or sheet of white paper. A *concave* lens, like

Fig. 86.



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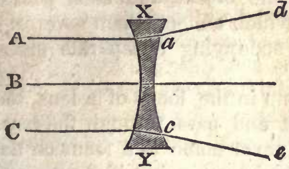
166. To what important and interesting uses is the power of light to undergo refraction converted? What instruments are used for this purpose? What is the office of a convex lens? Describe Fig. 86. Examples in a sun-glass and spectacles.

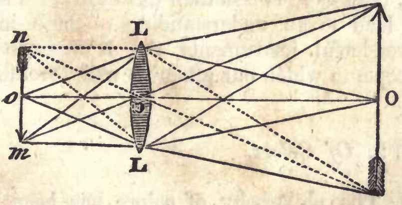
a convex mirror, *separates* rays of light. Thus, in Fig. 87, the solar beam is spread over a greater space on the screen than the size of the lens, indicating that the rays are separated from each other by passing through the lens. Hence, concave lenses do not form images as convex lenses do, and are therefore but little employed in the construction of optical instruments.

Fig. 87.



167. A convex lens, like a concave mirror, forms an *image* of an object without, by collecting all the pencils of rays that proceed from every point of the object and fall upon the lens, into corresponding points at the place of the image. The image is inverted because the pencils of rays cross each other, those from the top of the object going to the bottom of the image, and those from the bottom going to the top. In the figure, the central ray of each pencil (called the *axis*) and the extreme rays are represented. The ex-

Fig. 88.



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167. How does a convex lens form an image? Why is the image inverted? What is the *axis* of a pencil of rays? Where do the axes cross each other? Great number of rays that proceed from every point in the object.

treme rays cross each other in the center of the lens, and thus necessarily produce an inverted image; but we must conceive of a great number of rays proceeding from every point in the object, and each pencil covering the whole lens, which collects them severally into distinct points, each occupying a separate place in the image.

168. If we place a lamp in the focus of a lens, the rays that proceed from it and pass through the lens, go out parallel, and will never come to a focus on the other side, so as to form an image. But if we remove the lamp farther from the lens, so as to make the rays fall upon the lens in a state less diverging, then it will collect them into a distinct image on the other side, which image will be large in proportion as it is more distant from the lens. As the object is withdrawn from the lens, the image approaches it; when they are at equal distances from the lens, they are equal in size; but when the object is farther from the lens than the image, the image is less than the object. These principles lead to an understanding of those interesting and wonderful instruments, the Microscope and the Telescope, to which our attention will hereafter be directed.

SEC. 2. *Of Colors.*

169. The philosophy of colors has been unfolded chiefly by means of the *Prism*. A Prism is a triangular piece of glass, usually four or five inches long, presenting three plane smooth surfaces. When we look through the prism, all external objects appear in

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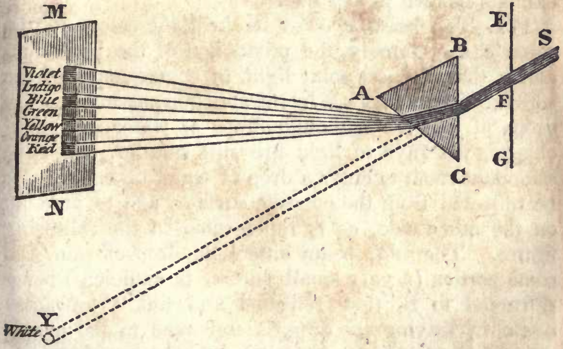
168. How do the rays go out when a lamp is placed in the focus? How when the lamp is farther from the lens than the focus? How is the size of the image affected by its distance from the lens? How is the image changed by withdrawing the lamp?

169. By what instrument has the philosophy of colors been unfolded? Define a prism. What appearances does it present when we

the most brilliant hues, diversified by the various colors of the rainbow. The reason of this is, that light consists of seven different colors, which, when in union with each other, compose white light; but when separated, appear each in its own peculiar hue. The different colors are as follows—violet, indigo, blue, green, yellow, orange, red. The prism separates the rays of solar light, in consequence of their having the property of undergoing different degrees of refraction in passing through it, the violet being turned most out of its course and the red least, and all the others differing among themselves in this respect, as is shown in the following diagram. E F represents the window shutter of a dark room, through a small opening in which a beam of solar rays shines. They fall on the prism, A B C, and are refracted, by which they are turned upward, but in different degrees, the red least and the violet most. By this means they are separated from each other, and lie one above another on the opposite wall, constituting

Fig. 89.



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look through it? Why? Seven colors of the spectrum. Why does the prism separate the different colors? Explain Fig. 89. How may we recompose the spectrum into white light?

the beautiful object called the *solar spectrum.* We may now introduce a double convex lens into the spectrum, just behind the prism, and collect all the rays which have been separated by the prism, and they will recompose white light. The elongated spectrum on the wall, presenting the seven primary colors, will vanish, and in the place of it will appear a round image of the sun as white as snow.

170. We may now learn the reason why so many different colors appear when we look through the prism. The leaves of a tree, for example, seem to send forth streams of red light on one side and of violet on the other. The intermediate colors lap over, and partly neutralize each other, while on the margin each color exhibits its own proper hue.

171. The *rainbow* owes its brilliant colors to the same cause, namely, the production of the individual colors that compose solar light, in consequence of the separation they undergo by refraction in passing through drops of water. Although drops of water are small objects, yet rays of light are still smaller, and have abundant room to enter a drop of water on one side, to be reflected from the opposite surface, and to pass out on the other side, as is represented in the following figure. The solar beam enters the drop of rain, and some portion (a very small portion is sufficient) being refracted to B, then reflected and finally refracted again in leaving the drop, is conveyed to the eye of the spectator. As in undergoing these two refractions, some rays are refracted more than others, consequently they are separated from each other, and coming to the eye of the spectator in this divided state, produce each

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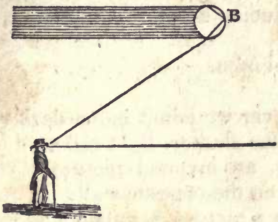
170. Why do so many different colors appear when we look through the prism? Explain the appearance of the leaves of a tree.

171. To what does the rainbow owe its colors? Explain how the separation of colors is produced. To what part of the bow does the line pass which joins the sun and the eye of the spectator? How high

its own color. The spectator stands with his back to the sun, and a straight line passing from the sun through the eye of the spectator, passes also through the center of the bow. When the sun is setting, so that this line becomes horizontal, the summit of the bow reaches an altitude of about 42°, and the bow is then a semicircle. When the sun is 42° high, the same line would pass 42° below the opposite horizon, and the summit of the bow would barely reach the horizon. When the sun is between these two altitudes, the bow rises as the sun descends, composing a larger and larger part of a circle, until, as the sun sets, it becomes an entire semicircle.

Fig. 90.



172. The varied colors that adorn the face of nature, as seen in the morning and evening cloud, in the tints of flowers, in the plumage of birds and wings of certain insects, and in the splendid hues of the precious gems, arise from the different qualities of different bodies in regard to the power of refracting or of reflecting light. When a substance reflects all the prismatic rays in due proportion, its color is white; when it absorbs them all, its color is black; and its color is blue,

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does the top of the bow reach when the sun is setting? Where is it when the sun is 42° above the western horizon? When the sun is between these two points?

green, or yellow, when it happens to reflect one of these colors, and to absorb all the others of the spectrum. These hues are endlessly varied by the power natural bodies have of reflecting a mixture of some of the primary colors to the exclusion of others, every new proportion producing a different shade.

SEC. 3. *Of Vision.*

173. Whenever we admit into a dark room through an opening in the shutter, light reflected from various objects without, an inverted picture of these objects will be formed on the opposite wall. A room fitted for exhibiting such a picture, is called a *Camera Obscura.* In a tower which has a window opening toward the east, upon a beautiful public square, containing churches and other public buildings, and numerous trees, and the various objects of a populous city, a little dark chamber is fitted up for a camera obscura, having a white concave stuccoed wall opposite to the window, ten feet from it, and all the other parts of the room painted black. The afternoon, when the sun is shining bright in the west, and all objects seen to the east present their enlightened sides toward the window, is the time for forming the picture. For this purpose, a round hole about three inches in diameter, is prepared in the shutter, which admits the only light that can enter the room. The room is made black everywhere except the wall that is to receive the picture, otherwise light would be reflected from different parts of the room upon the picture ; whereas it is essential to its distinctness, that the image should be unac-

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172. How are the colors of natural objects produced ? When is the color white, or red, or blue ? How are the colors varied ?

173. How may a picture be formed in a dark room ? What is it called ? Describe the Camera Obscura mentioned. When is the time for forming the picture ? Why is the room painted black, except the wall opposite the window ?

companied by light from any other source. The wall that is to receive the picture is made concave, so that every part of it may be equally distant from the orifice in the shutter.

174. We now close the shutter, and instantly there appears on the opposite wall a large picture, representing all the varied objects of the landscape seen from the window, as churches, houses, trees, men and women, carriages and horses, and in short every thing that is in view of the window, including the blue sky, and a few white clouds that are sailing through it. Each is represented in its proportionate size and color, and if it is moving, in its true motion. Two circumstances, only, impair the beauty of the picture; one is, that it is not perfectly distinct, the other, that it is inverted—the trees appear to grow downward, and the people to walk with their feet above their heads. The picture appears indistinct, because the opening in the shutter is so large that rays coming from different objects fall upon the picture and mix together, whereas each point in the image must be formed alone of rays coming from a corresponding point in the object. We will therefore diminish the size of the opening by covering it with a slide containing several holes of different sizes. We will first reduce the diameter to an inch. The picture is now much more distinct, but yet not perfectly well defined. We will therefore move the slide, and reduce the opening to half an inch. Now the objects are perfectly well defined, for through so small an opening none but the central ray, or axis, of each pencil can enter, and each axis will strike the opposite wall in a point distinct from all the rest. But though the picture is no longer confused, yet it lacks brightness, for so few rays scattered over so large a

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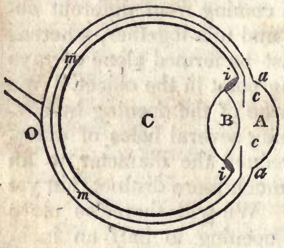
174. On closing the shutter, what appearances present themselves? What two circumstances impair the beauty of the picture? Why indistinct—How rendered more distinct—Why well defined

surface, are insufficient to form a bright image. We will now remove the slide, open the original orifice of three inches, which lets in a great abundance of light, and we will place immediately before the orifice, (within the room,) a convex lens of ten feet focus, which will collect all the scattered rays into separate foci, and thus form a picture at once distinct and bright, so that the most delicate objects without, as the trembling of the leaves of the trees, and the minutest motions of animals, are all very plainly discernible. Only one thing is wanting to make the picture perfect, and that is, to turn it right side upward. This may be done, and is done in some forms of the camera obscura ; but for our present purpose, which is to illustrate the principles of the eye, where the image formed is also inverted, it is better as it is.

Fig. 91.



175. The eye is a camera obscura, and the analogy between its principal parts and the contrivances employed to form a picture of external objects, as in the foregoing dark chamber, will appear very striking on comparison. Figure 91 represents the human eye, which is a circular chamber, colored black on all sides except the back part, called the *retina*, which is a delicate white membrane, like the finest gauze, spread to receive the image. The front part of the eye, A, is a lens of a shape exactly adapted to the purpose it is intended to serve, which projects

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when the orifice is small—What does the picture now lack ? How to make it at once well defined and bright ?

175. Analogy of the eye to the Camera Obscura. Describe the eye from Fig. 91.

forward so as to receive the light that comes in sidewise, and guides it into the eye. The *pupil* is an opening between *c* and *c*, like the opening in the window shutter, just behind which is a convex lens, B, which collects all the scattered rays, and brings each pencil to a separate focus, where they unite in forming a bright and beautifully distinct image of all external objects. O represents the *optic nerve*, by which the sensations made on the retina are conveyed to the brain. The substances with which the several parts of the eye, A, B, and C, are filled, are limpid and transparent, and purer than the clearest crystal.

176. It is essential to distinct vision, that the rays which enter the eye should be brought accurately to a focus at the place of the retina ; and in ninety-nine cases out of a hundred, this adjustment is perfect. But in a few instances, the lens, B, called the *crystalline humor*, is too convex, and then the image is formed before it reaches the retina. This is the case with near-sighted people. Their eyes are too convex ; but by wearing a pair of concave spectacles, they can destroy the excess of convexity in the eye, and then the crystalline lens will bring the light to a focus on the retina and the sight will be distinct. Sometimes, particularly as old age advances, the crystalline lens becomes less convex, and does not bring the rays to a focus soon enough, but they meet the retina before they have come accurately to a focus, and form a confused image. In this case a pair of convex spectacles aids the crystalline lens, and both together cause the image to fall exactly on the retina. As a piece of mechanism, the eye is unequalled for its beauty and perfection, and no part of the creation proclaims more distinctly both the existence and the wisdom of the Creator.

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176. What is essential to distinct vision ? Imperfection when the crystalline lens is too convex—how remedied—also when not convex enough—remedy ? Perfection of the eye.

SEC. 4. *Of the Microscope.*

177. The Microscope is an optical instrument, designed to aid the eye in the inspection of *minute* objects. The simplest microscope is a convex lens, like a spectacle glass. This, when applied to small objects, as the letters of a book, renders them both larger and more distinct. When an object is brought nearer and nearer to the eye, we finally reach a point within which vision begins to grow imperfect. That point is called the *limit of distinct vision.* Its distance is about five inches. If the object be brought nearer than this distance, the rays come to the eye too diverging for the lenses of the eye to bring them to a focus soon enough, so as to make their image fall exactly on the retina. Moreover, the rays which proceed from the extreme parts of the object, meet the eye too obliquely to be brought to the same focus with those rays which meet it more directly, and hence contribute only to confuse the picture.

178. We may verify these remarks by bringing gradually toward the eye a printed page with small letters. When the letters are within two or three inches of the eye, they are blended together and nothing is seen distinctly. If we now make a pin-hole through a piece of paper, and look at the same letters through this, we find them rendered far more distinct than before at near distances, and larger than ordinary. Their greater *distinctness* is owing to the exclusion of those oblique rays which, not being brought by the eye to the same focus with the central rays, only tend to confuse the image formed by the latter. As

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177. Define the microscope. What is the simplest form of the microscope? Its effect upon the letters of a book. What is the limit of distinct vision? Why do objects appear indistinct when nearer than this?

178. Example in a printed page—Appearance through a pin-hole. To what is the greater distinctness owing?—The increased brightness?

only the central rays of each pencil can enter so small an orifice, the picture is made up chiefly of the *axes* of all the pencils. These occupy each a separate point in the image, a point where no other rays can reach. The *increased magnitude* of the letters is owing to their being seen nearer than ordinary, and thus under a greater angle, and of course magnified.

179. A convex lens acts much on the same principles, but is still more effectual. It does not *exclude* the oblique rays, but it diminishes their obliquity so much as to enable the eye to bring them to a focus, at the distance of the retina, and thus makes them contribute to the *brightness* of the picture. The object is *magnified*, as before, because it is seen nearer, and consequently under a larger angle, so that the eye can distinctly recognise minute portions of the object, which were before invisible, because they did not occupy a sufficient space on the retina. Lenses have greater magnifying power in proportion as the convexity is greater, and of course the focal distance less. Since the magnifying power of the microscope arises from its enabling us to see objects nearer and under a larger angle, that power is increased in proportion as the focal distance is less than the limit of distinct vision. The latter being five inches, a lens which has a focal distance of one inch, by enabling us to see the object five times nearer, enlarges its length and breadth each five times, and its surface twenty-five times. Lenses have been made capable of affording a distinct image of very minute objects, when their focal distances were only one-sixtieth of an inch. In this case, the magnifying power would be as one-sixtieth to five;

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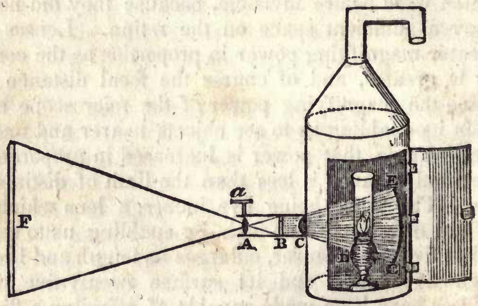
179. Explain the mode in which a convex lens acts. Why it makes objects appear brighter and larger. What lenses have the greatest magnifying power? Power of a lens of one inch focus—of one sixtieth of an inch focus.

or it would magnify the length and breadth each 300 times, and the surface 90,000 times.

180. The *Magic Lantern* and *Solar Microscope* owe their astonishing effects to the magnifying power of a simple lens. When the image so much exceeds the object in magnitude, were the object only enlightened by the common light of day, when it came to be diffused over so great a space, it would be very feeble, and the image would be obscure and perhaps invisible. The two instruments just named, have each an apparatus connected with the magnifying lens, which serves to illuminate the object highly, so that when the rays that proceed from it and form the enlarged image are spread over so great a space, they may still be sufficient to render the image bright and distinctly visible.

Fig. 92.



181. In the Magic Lantern, the illumination is afforded by a lamp, the light of which is reflected from a concave mirror placed behind it, which makes the light on that side return to unite with the direct light

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180. To what are the effects of the Magic Lantern and the Solar Microscope owing? Use of all the other parts of the apparatus, except the magnifier?

181. How is the illumination effected in the magic lantern? Describe Fig. 92. What sorts of objects are exhibited?

of the lamp, so that both fall on a large lens which collects them upon the object, thus strongly illuminating it. The foregoing diagram exhibits such a lantern, where the concave mirror behind is seen to reflect back the light to unite with that which proceeds directly from the lamp, so that both fall on the large convex lens at C, which collects them upon the object at B. This is usually painted in transparent colors on glass, and may be a likeness of some individual, small in the picture, but when magnified by the lens, A, and the image thrown on a screen or wall, F, will appear as large as life, and in strong colors; or the objects may be views of the heavenly bodies, which are thus often rendered very striking and interesting; or they may illustrate some department of natural history, as birds, fishes, or plants.

182. The *Solar Microscope* is the same in principle with the Magic Lantern, but the light of the sun instead of that of a lamp is employed to illuminate the object. As a powerful light may thus be commanded, very great magnifiers can be employed; for if the object is highly illuminated, the image will not be feeble or obscure when spread over a great space. By means of this instrument, the eels in vinegar, which are usually so small as to be invisible to the naked eye, may be made to appear six feet in length, and, as their motions as well as dimensions are magnified, they will appear to dart about with surprising velocity. The finest works of art, when exhibited in this instrument, appear exceedingly coarse and imperfect. The eye of a finished cambric needle appears full of rough projections; the blade of a razor looks like a saw; and the finest muslin exhibits threads as large as the cable of a ship. Thus, the small and almost invisible insect

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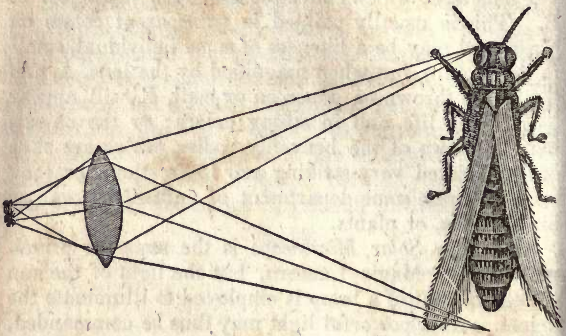
182. Solar Microscope, how it differs from the Magic Lantern—Why greater magnifiers can be used—appearance of the eels in vinegar. How do the works of art appear? How small insects?

represented in figure 93, gives out, when illuminated, so few rays, that when spread over the large surface of the image, the light would be too feeble to render the image visible; but, on strongly illuminating the insect by concentrating upon it a large beam of the sun's light, the image becomes distinct and beautiful, although perhaps a million times as large as the object. Even the minute parts of the insect, as the hairs on the legs, are revealed to us by the microscope.

Fig. 93.



Sec. 5. *Of the Telescope.*

183. The Telescope is an instrument employed for viewing *distant* objects. It aids the eye in two ways; first, by enlarging the angle under which objects are seen, and, secondly, by collecting and conveying to the eye a much larger amount of the light that proceeds from the object, than would enter the naked pupil. *We first form an image of a distant object, the*

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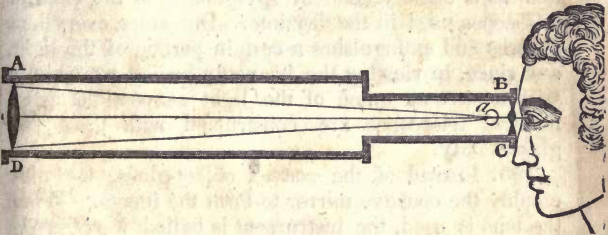
183. Define the Telescope. In what two ways does it aid the eye?

moon, for example, and then magnify that image by a microscope. The image may be formed either by a concave mirror or a convex lens, for both, as we have seen, form images. Although we cannot go to distant objects, as the moon and planets, so as to view them under the enlarged dimensions in which they would then appear, yet by applying a microscope to the image of one of those bodies, we may make it appear as it would do were we to come much nearer to it. To apply a microscope which magnifies a hundred times, is the same thing as to approach a hundred times nearer to the body.

Fig. 94.



184. Let A B C D represent the tube of the telescope. At the front end, or the end which is directed toward the object, (which we will suppose to be the moon,) is inserted a convex lens, L, which receives the rays of light from the moon, and collects them into the focus at *a*, forming an image of the moon. This image is viewed by a magnifier attached to the end, B C. The lens, L, is called the *object-glass*, and the microscope, in B C, the *eye-glass*. A few rays of light only from a distant object, as a star, can enter so small

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State the main principle of this instrument. How may the image be formed? How it brings objects nearer to us.

184. Describe the telescope as represented in Fig. 94. Point out the object-glass, and the eye-glass. What is the use of a large ob-

a space as the pupil of the eye; but a lens one foot in diameter will collect a beam of light equal to a cylinder of the same dimensions, and convey it to the eye. The object-glass merely forms an image of the object, but does not magnify; the microscope or eye-glass magnifies. By these means, many obscure celestial objects become distinctly visible, which would otherwise be too minute, or not sufficiently luminous, to be seen by us. A telescope like the foregoing, having simply an object-glass and an eye-glass, inverts objects, since the rays cross each other before they form the image. By employing more lenses, it may be turned back again, so as to appear in its natural position, as is usually done in spy-glasses, or the smaller telescopes used in the daytime. But since every lens absorbs and extinguishes a certain portion of the light, and since, in viewing the heavenly bodies, we usually wish to save as much of the light as possible, astronomical telescopes are constructed with these two glasses only.

185. Instead of the convex object-glass, we may employ the concave mirror to form the image. When the lens is used, the instrument is called a *refracting* telescope; when a concave mirror is used, it is called a *reflecting* telescope. Large reflectors are more easily made than large refractors, since a concave mirror may be made of any size; whereas, it is very difficult to obtain glass that is sufficiently pure for this purpose above a few inches in diameter, although Refractors are more perfect instruments than Reflectors, in proportion to their size. Sir William Herschel, a great astronomer of England, of the last century, made a

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ject-glass? Which glass collects the light—which magnifies? Can the image be made to appear erect? Why not done in the astronomical telescope?

185. Point out the distinction between refracting and reflecting telescopes. Give an account of Herschel's great telescope.

reflecting telescope forty feet in length, with a concave mirror more than four feet in diameter. The mirror alone weighed nearly a ton. So large and heavy an instrument must require a vast deal of machinery to work it and keep it steady; and accordingly, the framework surrounding it was formed of heavy timbers, and resembled the frame of a house. When one of the largest of the fixed stars, as Sirius, was entering the field of this telescope, its approach was announced by a bright dawn, like that which precedes the rising sun; and when the star itself entered the field, the light was too dazzling to be seen without a colored glass to protect the eye.

The telescope has made us acquainted with innumerable worlds, many of which are fitted up in a style of far greater magnificence than our own. To the interesting and ennobling study of these, let us next direct our attention.

RUDIMENTS

OF

NATURAL PHILOSOPHY AND ASTRONOMY.

PART II.

ASTRONOMY.

CHAPTER I.

DOCTRINE OF THE SPHERE.

DEFINITIONS—DIURNAL REVOLUTIONS.

186. Astronomy *is that science which treats of the heavenly bodies.* More particularly, its object is to teach what is known respecting the Sun, Moon, Planets, Comets, and Fixed Stars; and also to explain the methods by which this knowledge is acquired.

187. Astronomy is the oldest science in the world; but it was cultivated among the ancients chiefly for the purposes of Astrology. *Astrology was the art of foretelling future events by the stars.* Its disciples professed especially to be able to tell from the appearance of the stars at the time of any one's birth, what would be his course and destiny through life; and, respecting any country, and public events, what would be their fate, what revolutions they would undergo, what wars and other calamities they would suffer, or what good fortune they would experience. Visionary as

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186. Define Astronomy—What is its object?

187 **Antiquity of the science—For what purpose was it cultivated**

this art was, it nevertheless led to the careful observation and study of the heavenly bodies, and thus laid the foundations of the beautiful temple of modern astronomy.

188. Astronomy is a delightful and interesting study, when clearly understood ; but it is very necessary to a clear understanding of it, that the learner should think for himself, and labor to form an idea in his mind of the exact meaning of all the circles, lines, and points of the sphere, as they are successively defined ; and if any thing at first appears obscure, he may be assured that by patient thought it will clear up and become easy, and then he will understand the great machinery of the heavens as easily as he does that of a clock. "Patient thought," was the motto of Sir Isaac Newton, the greatest astronomer that ever lived ; and no other way has yet been discovered of obtaining a clear knowledge of this sublime science.

189. Let us imagine ourselves standing on a huge ball, (for such is the earth,) in a clear evening. Although the earth is large, compared with man and his works, yet it is very small, compared with the vast extent of the space in which the heavenly bodies move. When we look upward and around us at the starry heavens, we must conceive of ourselves as standing on a small ball, which is encircled by the stars on all sides of it alike, as is represented over the leaf ; and we must consider ourselves as bound to the earth by an invisible force, (gravity,) as truly as though we were lashed to it with cords. We are, therefore, in no more danger of falling off, than needles are of fall-

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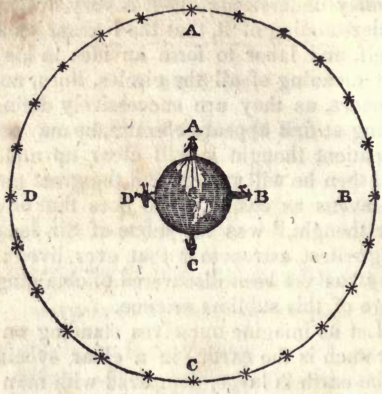
among the ancients? Define astrology. What did its disciples profess? To what good did it lead?

188. What is necessary to a clear understanding of Astronomy? What was the motto of Newton?

189. Where shall we imagine ourselves standing? What is said of the size of the earth? Are persons on the opposite side of the

ing from a magnet or loadstone, when they are attached to it on all sides. We must thus familiarize ourselves to the idea that *up* and *down* are not absolute directions

Fig. 95.



in space, but we must endeavor to make it seem to us up in all directions from the center of the earth, and down on all sides toward the center. If people on the opposite side of the globe seem to us to have their heads downward, we seem to them to have ours in the same position; and, twelve hours hence, we shall be in their situation and they in ours. We see but half the heavens at once, because the earth hides the other part from us; but if we imagine the earth to grow less and less until it dwindles to a point, so as not to obstruct our view in any direction, then we should see ourselves standing in the middle of a vast starry sphere, encompassing us alike on all sides. It is such a view

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earth in danger of falling off? What idea must we form of *up* and *down*? How should we view the heavens if the earth were so small as not to obstruct our view?

of the heavens that the astronomer has continually in the eye of his mind.

190. We are apt to bring along with us the first impressions of childhood; namely, that the sun, moon, and stars, are all fixed on the surface of the sky, which we imagine to be a real surface, like that of an arched ceiling; but it is time now to dismiss such childish notions, and to raise our thoughts to more just views of the creation. Our eyesight is so limited that we cannot distinguish between different distances, except for a moderate extent; beyond, all objects seem to us at the same distance, whether they are a hundred or a million miles off. The termination of this extent of our vision being at equal distances on all sides of us, we appear to stand under a vast dome, which we call the sky. The azure color of the sky, when clear, is nothing else than that of the atmosphere itself, which, though colorless when seen in a small volume, betrays a hue peculiar to itself when seen through its whole extent. Were it not for the atmosphere, the sky would appear black, and the stars would seem to be so many gems set in a black ground.

191. For the purpose of determining the relative situation of places, both on the earth and in the heavens, the various circles of the sphere are devised; but before contemplating the sphere marked up as artificial representations of it are, we must think of ourselves as standing on the earth, as on a point in the midst of boundless space, and see, with our mental eye, the pure sphere of the heavens, undefaced with any such rude lines. If we could place ourselves on any

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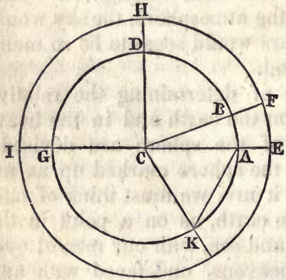
190. What erroneous conceptions are we apt to form in childhood of the sun, moon, and stars? Impossibility of distinguishing different distances by the eye. Under what do we appear to stand? To what is the blue color of the sky owing?

191. For what purpose are the circles of the sphere devised? What must we do before studying the artificial representations of the sphere? If we could stand on one of the stars, what should we

one of the stars, we should see a starry firmament over our heads, similar to that we see now. But although we obtain the most correct and agreeable, as well as the most sublime views of the heavenly bodies, when we think of them as they are in nature—bodies scattered at great distances from each other, through boundless space—yet we cannot make much progress in the science of astronomy, unless we learn the artificial divisions of the sphere. Let us, therefore, now turn our attention to these.

192. The definitions of the different lines, points, and circles, which are used in astronomy, and the propositions founded on them, compose the *doctrine of the sphere*. Before these definitions are given, let us attend to a few particulars respecting the method of measuring angles. (See Fig. 96.) A line drawn from the center to the circumference of a circle, is called a *radius*, as C D, C B, or C K. Any part of the circumference of a circle is called an *arc*, as A B, or B D. An *angle* is measured by an arc, included between two radii. Thus, in figure 96, the angle included between the two radii, C A and C B, that is, the angle A C B, is measured by the arc A B. Every circle is divided into 360 equal parts, called *degrees ;* and any arc, as A B, contains a certain number of degrees, according

Fig. 96.



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see ? When do we obtain the most agreeable and sublime views of the heavenly bodies ? What else is necessary to our progress ?

192. Define the doctrine of the sphere. What is the radius of a circle—an arc—an angle ? Explain by Fig. 96. Into how many de-

to its length. Thus, if an arc, A B, contains 40 degrees, then the opposite angle is said to be an angle of 40 degrees, and to be measured by A B. But this arc is the same part of the smaller circle that E F is of the greater. The arc A B, therefore, contains the same number of degrees as the arc E F, and either may be taken as the measure of the angle A C B. As the whole circle contains 360 degrees, it is evident that the quarter of a circle, or *quadrant*, contains 90 degrees, and that the semi-circle contains 180 degrees.

193. A section of a sphere, cut through in any direction, is a circle. *Great circles* are those which pass through the center of a sphere, and divide it into two equal hemispheres. *Small circles* are such as do not pass through the center, but divide the sphere into two unequal parts. This distinction may be easily exemplified by cutting an apple first through the center, and then through any other part.* The first section will be a great, and the second a small circle. The *axis* of a circle is a straight line passing through its center at right angles to its plane. If you cut a circle out of pasteboard, and thrust a needle through the center, perpendicularly, it will represent the axis of the circle. The *pole* of a great circle, is the point on the sphere where its axis cuts through the sphere. Every great circle has two poles, each of which is everywhere 90 degrees from that circle. All great circles of the sphere cut each other in two points, diametrically opposite, and consequently their points of section are 180 degrees

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* It is strongly recommended that young learners be taught to verify the definitions in the manner here proposed.

grees is every circle divided ? Does the arc of a small circle contain the same number of degrees as the corresponding arc of a large circle ? How many degrees in a quadrant—in a semi-circle ?

193. What figure does any section of a sphere produce ? Define *great* circles—*small* circles. How may this distinction be exemplified ? Define the axis of a circle—the pole. How many poles has every great circle ? How many degrees is the pole from the circum-

apart. Thus, if we cut the apple through the center, in two different directions, we shall find that the points where the circles intersect one another, are directly opposite to each other, and hence the distance between them is half round the apple, and, of course, 180 degrees. A point on the sphere, 90 degrees distant from any great circle, is the *pole* of that circle ; and every circle on the globe, drawn from the pole to the circumference of any circle, is at *right angles* to it. Such a circle is called a *secondary* of the circle through whose pole it passes.

194. In order to fix the position of any place, either on the surface of the earth or in the heavens, both the earth and the heavens are conceived to be divided into separate portions, by circles which are imagined to cut through them in various ways. The earth, thus intersected, is called the *terrestrial*, and the heavens the *celestial* sphere. The great circles described on the earth, extended to meet the concave sphere of the heavens, become circles of the celestial sphere.

The *Horizon* is the great circle which divides the earth into upper and lower hemispheres, and separates the visible heavens from the invisible. This is the *rational* horizon : the *sensible* horizon is a circle touching the earth at the place of the spectator, and is bounded by the line in which the earth and sky seem to meet. The poles of the horizon are the *zenith* and *nadir*. The zenith is the point directly over our heads ; the nadir, that directly under our feet. The plumb-line, (such as is formed by suspending a bullet by a string,) coincides with the axis of the horizon, and consequently is directed toward its poles. Every

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ference ? How does a great circle passing through the pole of another great circle cut the circle ? What is such a circle called ?

194. How are the earth and heavens conceived to be divided ? What is the terrestrial, and what the celestial sphere ? How do terrestrial circles become celestial ? Define the horizon. Distinguish between the rational and the sensible horizon. Define the zenith

place on the surface of the earth has its own horizon; and the traveller has a new horizon at every step, always extending 90 degrees from him in every direction.

195. *Vertical* circles are those which pass through the poles of the horizon, (the zenith and nadir,) perpendicular to it. The *Meridian* is that vertical circle which passes through the north and south points. The *Prime Vertical*, is that vertical circle which passes through the east and west points. The *altitude* of a heavenly body, is its elevation above the horizon, measured on a vertical circle; the *azimuth* of a body is its distance, measured on the horizon, from the meridian to a vertical circle passing through that body; and the *amplitude* of a body is its distance, on the horizon, north or south of the prime vertical.

196. In order to make these definitions intelligible and familiar, I invite the young learner, who is anxious to acquire clear ideas in astronomy, to accompany me some fine evening under the open sky, where we can have an unobstructed view in all directions. A ship at sea would afford the best view for our purpose, but a level plain of great extent will do very well. We carry the eye all round the line in which the sky seems to rest upon the earth: this is the horizon. I hold a line with a bullet suspended, and this shows me the true direction of the axis of the horizon; and I look upward in the direction of this line to the zenith, directly over my head, and downward toward the nadir. If I mark the position of a star exactly in the zenith, as indicated by the position of the plumb-line,

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and nadir. Toward what points is the plumb line directed? How many horizons can be imagined?

195. Define vertical circles—the meridian—the prime vertical—altitude—azimuth—amplitude.

196. What is proposed in order to make these definitions intelligible and familiar? What situation would afford the best view? Describe how we shall successively denote the position of the axis of

and then turn round and look upward toward the zenith, I shall probably not see the star, because I do not look high enough. Most people will find, if they first fix upon a star as being in the zenith when their faces are toward the south, and then turning round to the north, fix upon another star as near the zenith, (without reference to the first,) they will find that the two stars are several degrees apart, the true zenith being half way between them. This arises from the difficulty of looking directly upward.

197. Having fixed upon the position of the zenith, I will point my finger to it, and carry the finger down to the horizon, repeating the operation a number of times, from the zenith to different points of the horizon: the arcs which my finger may be conceived to trace out on the face of the sky, are arcs of vertical circles. I will now direct my finger toward the north point of the horizon, (having previously ascertained its position by a compass,) and carry it upward through the zenith, and down to the south point of the horizon: this is the meridian. From the south point, I carry my finger along the horizon, first toward the east, and then toward the west, and I measure off arcs of azimuth. I might do the same from the north point, for azimuth is reckoned east and west from either the north or the south point. I will again direct my finger to the western point of the horizon, and carry it upward through the zenith to the east point, and I shall trace out the prime vertical. From this, either on the eastern or the western side, if I carry my finger along the horizon, north and south, I shall trace out arcs of amplitude. I will finally fix

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the horizon—the zenith and nadir. Difficulty of looking directly to the zenith.

197. How to mark out with the finger vertical circles—the meridian—arcs of azimuth—the prime vertical—arcs of amplitude—arcs of altitude?

my eye on a certain bright star, and try to determine how far it is above the horizon. This will be its altitude. It appears to be about one third of the way from the horizon to the zenith; then its altitude is 30 degrees. But we are apt to estimate the number of degrees near the horizon too large, and near the zenith too small, and therefore I look again more attentively, making some allowance for this source of error, and I judge the altitude of the star to be about 27 degrees, and of course its zenith distance 63 degrees.

198. The *Axis of the earth*, is the diameter on which the earth is conceived to turn in its daily revolution from west to east. The same line continued until it meets the concave of the heavens, constitutes the *axis of the celestial sphere*. We will take a large round apple, and run a knitting-needle through it in the direction of the eye and stem. The part of this that lies within the apple, represents the axis of the earth, and its prolongation (conceived to be continued to the sky,) the axis of the heavens. We do not suppose that there is any such actual line on which the earth turns, any more than there is in a top on which it spins; but it is nevertheless convenient to imagine such a line, and to represent it by a wire.* The *poles of the earth* are the extremities of the earth's axis; the *poles of the heavens* are the extremities of the celestial axis.

199. The *Equator* is a great circle, cutting the axis of the earth at right angles. The intersection of the plane of the equator with the surface of the earth, con-

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* Experience shows that it is necessary to guard young learners from the error of supposing that our artificial representations of the sphere actually represent things as they are in nature.

198. Define the axis of the earth—axis of the celestial sphere. How are both represented by means of an apple? Is there any such actual line on which the earth turns? Distinguish between the poles of the earth and the poles of the heavens.

stitutes the *terrestrial*, and its intersection with the concave sphere of the heavens, the *celestial* equator. We have before seen (Art. 195) that every place on the earth has its own horizon. Wherever one stands on the earth, he seems to be in the center of a circle which bounds his view. If he is at the equator, this circle passes through both the poles; or, in other words, at the equator the poles lie in the horizon. Let us imagine ourselves standing there on the 21st of March, when the sun rises due east and sets due west, and appears to move all day in the celestial equator, and let us think how it would seem to see the sun, at noon, directly over our heads, and at night to see the north star just glimmering on the north point of the horizon. If we sail northward from the equator, the north star rises just as many degrees above the horizon as we depart from the equator; so that by the time we reach the part of the globe where we live, the north star has risen almost half way to the zenith, and the axis of the sphere which points toward the north star, seems to have changed its place as we have changed ours, and to have risen up so as to make a large angle with the horizon, and the sun no longer mounts to the zenith at noon.

200. Now it is not the earth that has shifted its position; this constantly maintains the same place, and so does the equator and the earth's axis. Our horizon it is that has changed; as we left the equator, a new horizon succeeded at every step, reaching constantly farther and farther beyond the pole of the earth, or dipping constantly more and more below the celestial pole; but being insensible of this change in our hori-

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199. Define the equator. Distinction between the terrestrial and the celestial equator. Where do the poles of the equator lie? How would the sun appear to move to a spectator on the equator? Where would the north star appear? How, when we sail northward from the equator? What apparent change in the earth's axis?

200. What has caused these changes? If we sail quite to the north

zon, the pole it is that seems to rise, and if we were to sail quite to the north pole of the earth, the north star would be directly over our heads, and the equator would have sunk quite down to the horizon; and now the sun, instead of mounting up to the zenith at noon, just skims along the horizon all day; and, at night, at seasons of the year when the sun is south of the equator, all the stars appear to revolve in circles parallel to the horizon, the circles of revolution continually growing less as we look higher and higher, until those stars which are near the zenith scarcely appear to revolve at all. Those who sail from the equator toward the pole, and see the apparent paths of the sun and stars change so much, can hardly help believing that those bodies have been changing their courses; but all these appearances arise merely from the spectator's changing his own horizon, that is, constantly having new ones, which cut the axis of the earth at different angles.

201. The *Latitude* of a place on the earth, is its distance from the equator, north or south. The *Longitude* of a place is its distance from some standard meridian, east or west. The meridian usually taken as the standard, is that of the observatory of Greenwich, near London; and when we say that the longitude of New York is 74 degrees, we mean that the meridian of New York cuts the equator 74 degrees west of the point where the meridian of Greenwich cuts it.

202. The *Ecliptic* is the great circle in which the earth performs its annual revolution around the sun. It passes through the center of the earth and the center of the sun. It is found, by observation, that the earth does not lie with its axis perpendicular to the

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pole, where will the north star appear? Where the equator? How would the sun and stars appear to revolve in their daily progress?

201. Define the latitude of a place on the earth—the longitude—from what place is it reckoned?

plane of the ecliptic, so as to make the equator coincide with it, but that it is turned about 23½ degrees out of a perpendicular direction, making an angle with the plane itself of 66½ degrees. The equator, therefore, must be turned the same distance out of a coincidence with the ecliptic, the two circles making an angle with each other of 23½ degrees. The *Equinoctial Points*, or *Equinoxes*, are the points where the ecliptic and equator cross each other. The time when the sun crosses the equator in going northward, is called the *vernal*, and in returning southward, the *autumnal* equinox. The vernal equinox occurs about the 21st of March, and the autumal about the 22d of September. The *Solstitial Points* are the two points of the ecliptic most distant from the equator. The times when the sun comes to them are called the *Solstices*. The summer solstice occurs about the 22d of June, and the winter solstice about the 22d of December.

203. The ecliptic is divided into twelve equal parts, of 30 degrees each, called *Signs*, which, beginning at the vernal equinox, succeed each other in the following order, being each distinguished by characters or symbols, by which the student should be able to recognise the signs to which they severally belong whenever he meets with them.

1. Aries,	♈	7. Libra,	♎
2. Taurus,	♉	8. Scorpio,	♏
3. Gemini,	♊	9. Sagittarius,	♐
4. Cancer,	♋	10. Capricornus,	♑
5. Leo,	♌	11. Aquarius,	♒
6. Virgo,	♍	12. Pisces,	♓

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202. Define the ecliptic. What is the angle of inclination of the ecliptic to the equator? What are the equinoctial points or equinoxes—the vernal equinox—the autumnal—the solstitial points—the solstices? When do they occur?

203. How is the ecliptic divided? Name the signs of the zodiac and recognise each by its character.

204. The position of a heavenly body is referred to by its right ascension and declination, as in Geography we determine the situation of places by their latitudes and longitudes. *Right Ascension* is the angular distance from the vernal equinox, reckoned on the celestial equator, as we reckon longitude on the terrestrial equator from Greenwich. *Declination* is the distance of a body from the celestial equator, either north or south, as latitude is counted from the terrestrial equator. *Celestial Longitude* is reckoned on the ecliptic from the vernal equinox, and celestial *Latitude* from the ecliptic, north or south.

205. *Parallels of Latitude* are small circles parallel to the equator. They constantly diminish in size, as we go from the equator to the pole. The *Tropics* are the parallels of latitude which pass through the solstices. The northern tropic is called the tropic of Cancer; the southern, the tropic of Capricorn. The *Polar Circles* are the parallels of latitude that pass through the poles of the ecliptic, 23½ degrees from the poles of the earth. That portion of the earth which lies between the tropics, on either side of the equator, is called the *Torrid Zone;* that between the tropics and the polar circles, the *Temperate Zone;* and that between the polar circles and the poles, the *Frigid Zone.* The *Zodiac* is the part of the celestial sphere which lies about eight degrees on each side of the ecliptic. This portion of the heavens is thus marked off by itself because the paths of the planets are confined to it.

206. After having endeavored to form the best idea we can of the circles, and of the foregoing definitions relating to the sphere, we shall derive much aid from

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204. Define right ascension—declination—celestial longitude—celestial latitude.

205. Parallels of latitude—how do they change as we go from the equator? The tropics—polar circles—torrid zone—temperate zone—frigid zones—zodiac.

inspecting an artificial globe, and seeing how these various particulars are represented there. But every learner, however young, can adopt, with great advantage, the following easy device for himself. To represent the earth, select a large apple, (a melon, when in season, will be found still better.) The eye and the stem of the apple will indicate the position of the two poles of the earth. Applying the thumb and finger of the left hand to the poles, and holding the apple so that the poles may be in a north and south line, turn this little globe from west to east, and its motion will correspond to the daily motion of the earth. Pass a wire or a knitting-needle through the poles, and it will represent the *axis* of the sphere. A circle cut round the apple half way between the poles, will be the *equator;* and several other circles cut between the equator and the poles, parallel to the equator, will represent *parallels of latitude;* of which two, drawn 23½ degrees from the equator, will be the *tropics,* and two others, at the same distance from the poles, will be the *polar circles.* The space between the tropics, on both sides of the equator, will be the *torrid zone;* between the tropics and polar circles, the two *temperate zones;* and between the polar circles and the poles, the two *frigid zones.* A great circle cut round the apple, passing through both poles, in a north and south direction, will represent the *meridian,* and several other great circles drawn through the poles, and, of course, perpendicularly to the equator, will be secondaries to the equator, constituting meridians, or *hour circles.* A great circle, cut through the center of the apple, from one tropic to the other, would represent the *plane* of the

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206. After forming as clear an idea as we can of the divisions of the sphere, to what aids shall we resort? How shall we represent the earth—its poles—the daily motion—axis—equator—parallels of latitude—tropics—polar circles—zones—meridians or hour circles—solstices—equinoctial points?

ecliptic, and its intersection with the surface of the apple, would be the *terrestrial* ecliptic. The points where this circle meets the tropics, indicate the position of the *solstices;* and its intersections with the equator, the *equinoctial points.*

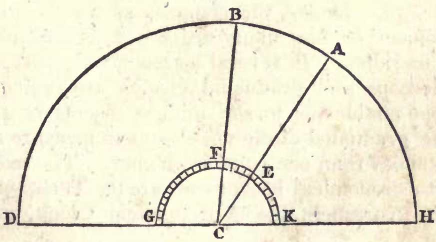
CHAPTER II.

ASTRONOMICAL INSTRUMENTS AND OBSERVATIONS.

TELESCOPE—TRANSIT INSTRUMENT—ASTRONOMICAL CLOCK—SEXTANT.

207. WHEREVER we are situated on the surface of the earth, we appear to be in the center of a vast sphere, on the concave surface of which all celestial objects are inscribed. If we take any two points on the surface of the sphere, as two stars, for example, and imagine straight lines to be drawn from them to the eye, the angle included between these lines will be measured by the arc of the sky contained between the two points. Thus, if D B H, Fig. 97, represents the con-

Fig. 97.



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207. How to measure the angular distance between two stars. Illustrate by Fig. 97. Why may we measure the angle on the small circle G F K?

cave surface of the sphere, A, B, two points on it, as two stars, and C A, C B, straight lines drawn from the spectator to those points, then the angular distance between them is measured by the arc A B, or the angle A C B. But this angle may be measured on a much smaller circle, G F K, since the arc E F will have the same number of degrees as the arc A B.

208. The simplest mode of taking an angle between two stars, is by means of an arm opening at the joint like the blade of a penknife, the end of the arm moving like C E upon the graduated circle G F K. In fact, an instrument constructed on this principle, resembling a carpenter's rule with a folding joint, with a semicircle attached, constituted the first rude apparatus for measuring the angular distance between two points on the celestial sphere. Thus, the sun's elevation above the horizon might be ascertained by placing one arm of the rule on a level with the horizon, and bringing the edge of the other into a line with the sun's centre. The common surveyor's compass affords a simple example of angular measurement. Here the needle lies in a north and south line, while the circular rim of the compass, when the instrument is level, corresponds to the horizon. Hence, the compass shows the *azimuth* of an object, or how many degrees it is east or west of the meridian. In several astronomical instruments, the telescope and graduated circles are united; the telescope enables us to see minute objects or points, and the graduated circle enables us to measure angular distances from one point to another. The most important astronomical instruments are the Telescope, the Transit Instrument, the Astronomical Clock, and the Sextant.

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208. What is the simplest mode of taking the angle between two stars? Example of angular measurement by the surveyor's compass. What angle or arc does it measure? Why do some instruments unite the telescope with a graduated circle?

209. The *Telescope* has been already described and its principles explained, (Art. 184.) We have seen that it aids the eye in two ways: first, by collecting and conveying to the eye a larger beam of light than would otherwise enter it, thus rendering objects more distinct, and many visible that would otherwise be invisible for want of sufficient light; and, secondly, by enlarging the angle under which objects are seen, and thus bringing distinctly into view such as are invisible, or obscure to the naked eye from their minuteness. When the telescope is used by itself, it is for obtaining brighter and more enlarged views of the heavenly bodies, especially the moon and planets. With the larger kinds of telescopes, we obtain many grand and interesting views of the heavens, and see millions of worlds revealed to us that are invisible to the naked eye.

210. The *Transit Instrument* (Fig. 98, p. 198) is a telescope firmly fixed on a stand, so as to keep it perfectly steady, and permanently placed in the meridian. The object of it is to determine when bodies cross the meridian, or make their *transit* over it; or, in other words, to show the precise instant when the center of a heavenly body is on the meridian. The *Astronomical Clock* is the constant companion of the transit instrument. This clock is so regulated as to keep exact pace with the stars, which appear to move round the earth from east to west once in twenty-four hours, in consequence of the earth turning on its axis in the same time from west to east. The time occupied in one complete revolution of the earth, (which is indicated by the interval occupied by a star from the me-

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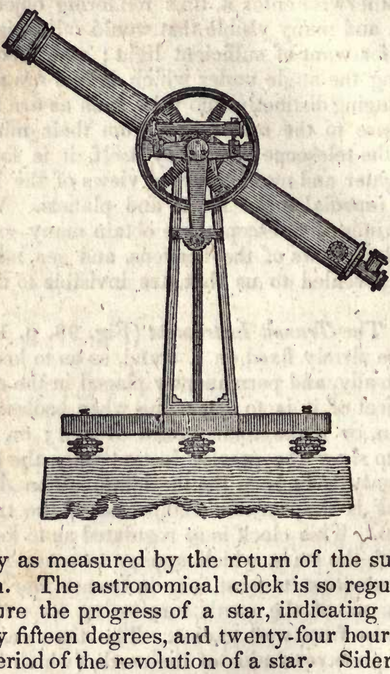
209. How does the telescope aid the eye? When the telescope is used by itself, for what purpose is it? What views do we obtain with the larger kinds of telescopes?

210. Define the Transit Instrument. What is the object of it? What does it show? What instrument accompanies it? With what does the astronomical clock keep pace? What occasions the

ridian round to the meridian again,) is called a *sidereal* day. It is, as we shall see hereafter, shorter than the solar day as measured by the return of the sun to the meridian. The astronomical clock is so regulated as to measure the progress of a star, indicating an hour for every fifteen degrees, and twenty-four hours for the whole period of the revolution of a star. Sidereal time commences when the vernal equinox is on the meridian, just as solar time commences when the sun is on the meridian.

Fig. 98.



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apparent movement of the stars from east to west? Define a sidereal day. To how many degrees does an hour correspond? When does sidereal time commence?

211. Any thing becomes a measure of time which divides duration equally. The celestial equator, therefore, is precisely adapted to this purpose, since, in the daily revolution of the heavens, equal portions of it pass under the meridian in equal times. The only difficulty is, to ascertain the amount of these portions for given intervals. Now the astronomical clock shows us exactly this amount, for, when regulated to sidereal time, the hour hand keeps exact pace with the vernal equinox, revolving once on the dial plate of the clock while the equator turns once by the revolution of the earth. The same is true, also, of all the small circles of diurnal revolution: they all turn exactly at the same rate as the equator, and a star situated anywhere between the equator and the pole, will move in its diurnal circle along with the clock, in the same manner as though it were in the equator. Hence, if we note the interval of time between the passage of any two stars, as shown by the clock, we have a measure of the number of degrees by which they are distant from each other in right ascension. We see now how easy it is to take arcs of right ascension: the transit instrument shows us when a body is on the meridian; the clock indicates how long it is since the vernal equinox passed it, which is the right ascension itself. (Art. 204.) It also tells us the *difference* of right ascension between any two bodies, simply by indicating the difference in time between their periods of passing the meridian. I observed a star pass the central wire of the transit instrument (which was exactly in the meridian) three hours and fifteen minutes of sidereal time; hence, as one hour equals fifteen degrees, three hours

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211. How may any thing become a measure of time? Why is the celestial equator peculiarly adapted to this purpose? What is the only difficulty? How does the astronomical clock show us what portion of the equator passes under the meridian? Do the parallels of latitude turn at the same rate with the equator? How do we measure the difference of right ascension between two stars, by means

and a quarter must have equalled forty-eight degrees and three quarters, which was the right ascension of the star. Two hours and three quarters afterward, that is, at six hours sidereal time, I observed another star cross the meridian. Its right ascension must have been ninety degrees, and consequently the difference of right ascension of the two, forty-one and a quarter degrees.

212. Again, it is easy to take the *declination* of a body when on the meridian. By declination, we must recollect, is meant the distance of a body north or south of the celestial equator. When a star is crossing the meridian line of the transit instrument, the point of the meridian toward which the telescope is directed at that instant, will be shown on the graduated circle of the instrument, and the distance of that point from the zenith, subtracted from the latitude of the place of observation, will give the declination of the star. We have before seen, that when we have found the right ascensions and declinations of the heavenly bodies, we may lay down their relative situations on a map, just as we do those of places on the earth by their latitudes and longitudes.

213. The *Sextant* is an instrument used for taking the angular distance of one point from another on the celestial sphere. It is particularly valuable for measuring celestial arcs at sea, because it is not, like most astronomical instruments, affected by the motion of the ship. The principle of the sextant may be briefly described as follows: it gives the angular distance between any two objects on the celestial sphere, by reflecting the image of one of the objects so as to coin-

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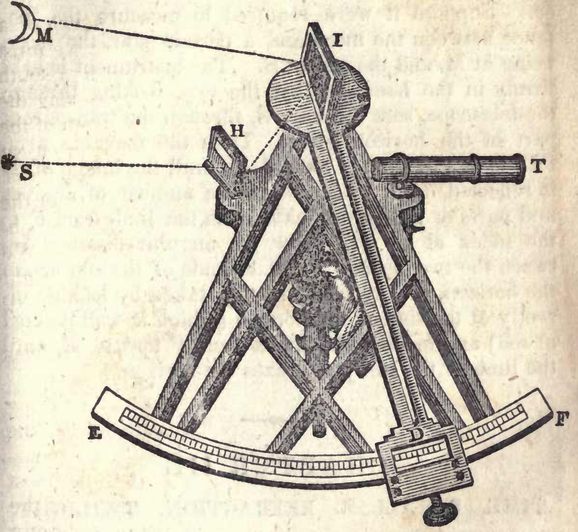
of the clock? Describe the mode of taking right ascensions with the transit instrument and clock.

212. What is the declination of a body? How taken when on the meridian?

213. For what is the Sextant used? For what is it particularly

cide with the other object as seen by the naked eye. The arc through which the reflector is turned to bring the reflected object to coincide with the other object, becomes a measure of the angular distance between them. The instrument is of a triangular shape, and is made strong and firm by metallic cross-bars. It has two small mirrors, I, H, called respectively, the index glass and the horizon glass, both of which are firmly fixed perpendicularly to the plane of the instrument. The index glass is attached to the movable arm, I D, and turns as this is moved along the gradu-

Fig. 99.



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valuable? State its principle. Describe the Sextant. Point out the Index glass and the Horizon glass. State the use of the Vernier.

ated limb, E F. This arm carries a *Vernier* at D, a contrivance which enables us to read off minute parts of the spaces into which the limb is divided. The horizon glass, H, consists of two parts; the upper part being transparent or open, so that the eye looking through the telescope, T, can see through it a distant object, as a star, at S, while the lower part is a reflector. Suppose it were required to measure the distance between the moon and a certain star, the moon being at M, and the star at S. The instrument is held firmly in the hand, so that the eye, looking through the telescope, sees the star, S, through the transparent part of the horizon glass. Then the movable arm, I D, is moved from F toward E, until the image of M is reflected down to S; when the number of degrees and parts of a degree reckoned on the limb from F to the index at D, will show the angular distance between the two bodies. The altitude of the sun above the horizon, at any time, may be taken by looking directly at the line of the horizon (which is well defined at sea) and moving the index from F toward E, until the limb of the sun just grazes the horizon.

CHAPTER III.

TIME. PARALLAX. REFRACTION. TWILIGHT.

SIDEREAL AND SOLAR DAYS—MEAN AND APPARENT TIME—HORIZONTAL PARALLAX—LENGTH OF TWILIGHT IN DIFFERENT COUNTRIES.

214. As time is a measured portion of indefinite duration, any thing or any event which takes place at equal intervals, may become a measure of time. But the great standard of time is the period of the revolu-

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Describe the Horizon glass. Describe the mode of taking an observation with the Sextant. How to take the sun's altitude.

tion of the earth on its axis, which, by the most exact observations, is found to be always the same. The time of the earth's revolution on its axis, as already explained, is called a sidereal day, and is determined by the apparent revolution of a star in the heavens. This interval is divided into twenty-four *sidereal* hours.

215. *Solar* time is reckoned by the apparent revolution of the sun from noon to noon, that is, from the meridian round to the meridian again. Were the sun stationary in the heavens like a fixed star, the time of its apparent revolution would be equal to the revolution of the earth on its axis, and the solar and sidereal days would be equal. But since the sun passes from west to east, in his apparent annual revolution around the earth, three hundred and sixty degrees in three hundred and sixty-five days, he moves eastward nearly a degree a day. While, therefore, the earth is turning once on its axis, the sun is moving in the same direction, so that when we have come round under the same celestial meridian from which we started, we do not find the sun there, but he has moved eastward nearly a degree, and the earth must perform so much more than one complete revolution, before our meridian cuts the sun again. Now, since we move in the diurnal revolution, fifteen degrees in sixty minutes, we must pass over one degree in four minutes. It takes, therefore, four minutes for us to *catch up* with the sun, after we have made one complete revolution. Hence, the solar day is almost four minutes longer than the sidereal; and if we were to reckon the sidereal day twenty-four hours, we should reckon the solar day twenty-four hours and four minutes. To suit the pur-

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214. What may become a measure of time? What is the great standard of time?

215. Distinguish between sidereal and solar time. Why are the solar days longer than the sidereal? How much longer? If we count the solar day twenty-four hours, how long is the sidereal day?

poses of society at large, however, it is found more convenient to reckon the solar day twenty-four hours, and throw the fraction into the sidereal day. Then,

24h 4m : 24h : : 24h : 23h 56m 4s.

That is, when we reduce twenty-four hours and four minutes to twenty-four hours, the same proportion will require that we reduce the sidereal day from twenty-four hours to twenty-three hours fifty-six minutes four seconds; or, in other words, a sidereal day is such a part of a solar day.

216. The solar days, however, do not always differ from the sidereal by precisely the same fraction, since they are not constantly of the same length. Time, as measured by the sun, is called *apparent* time, and a clock so regulated as always to keep exactly with the sun, is said to keep apparent time. But as the sun in his apparent motion round the earth once a year, goes sometimes faster and sometimes slower, a clock which always keeps with the sun must vary its motion accordingly, making some days longer than others. The *average* length of all the solar days throughout the year, constitutes *Mean Time.* Clocks and watches are commonly regulated to mean time, and therefore do not keep exactly with the sun, but are sometimes faster and sometimes slower than the sun. If one clock is so constructed as to keep exactly with the sun, and another clock is regulated to mean time, the difference between the two clocks at any period is the *equation of time* for that period. The two clocks would differ most about the third of November, when the apparent time is sixteen and a quarter minutes faster than the mean time. But since apparent time is at one time greater and at another less than mean time, the two

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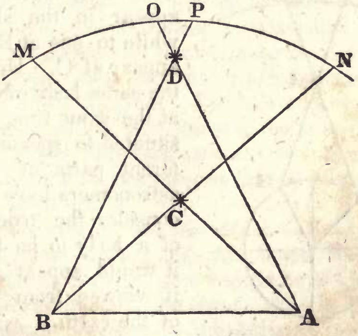
216. Do the solar days always differ from the sidereal by the same fraction? What is apparent time? When is a clock said to keep apparent time? What constitutes mean time? How are clocks and watches commonly regulated? What is the equation of time? When would the two clocks differ most, and how much? When would they be together?

must obviously be sometimes equal to each other. This is the case four times a year; namely, April 15th, June 15th, September 1st, and December 24th.

217. As a day is the period of the revolution of the earth on its axis, so a *year* is the period of the revolution of the earth around the sun. This time, which constitutes the astronomical year, has been ascertained with great exactness, and found to be 365d. 5h. 48m. 51sec. The ancients omitted the fraction, and reckoned it only 365 days. Their year, therefore, would end about six hours before the sun had completed his apparent revolution in the ecliptic, and, of course, be so much too short. In four years they would disagree a whole day. This is the reason why every fourth year is made to consist of 366 days, by reckoning 29 days in February instead of 28. This fourth year the ancients called *Bissextile*—we call it *Leap year*.

Fig. 100.



218. PARALLAX *is the apparent change of place which objects undergo by being viewed from different points.*

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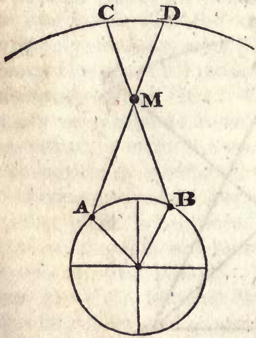
217. What period is a year? What is its exact length? How long did the ancients reckon it? Explain why every fourth year is reckoned 366 days.

All objects beyond a certain moderate height above us, appear to be projected on the face of the sky; but spectators at some distance from each other refer the same body to different points of the sky. Thus, if M N (Fig. 100) represents the sky, and C and D two bodies in the atmosphere, a spectator at A would refer C to M, while one at B would refer it to N. The arc, M N, would measure the angle of the parallax. In the same manner, O P would measure the angle of parallax of the body D. It is evident from the figure, that nearer objects have a much greater parallax than those that are remote. Indeed, the fixed stars are so distant, that two spectators a hundred millions of miles apart would refer a given star to precisely the same part of the heavens. But the moon is comparatively near, and her apparent place in the sky, at a given time, is much affected by parallax. Thus, to a spectator at A, the moon would appear in the sky at D, while to one at B, it would appear at C. Hence, since the same body often appears at the same time differently situated to spectators in different parts of the earth, astronomers have agreed to consider the true situation of a body to be that where it would appear in the sky if viewed from the center of the earth.

Fig. 101.



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218. Define parallax. Where do all objects at a certain height appear to be projected? How is the same body projected by different spectators? When have objects a large and when a small parallax? What is said of the fixed stars? Of the moon? What do astronomers consider the true place of a body?

219. The change of place which a body seen in the horizon, by a spectator on the surface of the earth, would undergo if viewed from the center, is called *horizontal parallax.* Although we cannot go to the center of the earth to view it, yet we can determine by the aid of geometry where it would appear if seen from the center, and hence we can find the amount of the horizontal parallax of a heavenly body, as the sun or moon. When we know the horizontal parallax of a heavenly body, we can ascertain its *distance* from us; but the method of doing this cannot be clearly understood without some knowledge of trigonometry.

220. REFRACTION *is a change of place which the heavenly bodies seem to undergo, in consequence of the direction of their light being altered in passing through the atmosphere.* As a ray of light traverses the atmosphere, it is constantly bent more and more, by the refraction of the atmosphere, out of its original direction. Now an object always appears in that direction in which the light from it finally comes to the eye. By refraction, therefore, the heavenly bodies are all made to appear higher than they really are, especially when they are near the horizon. The sun and moon, when near rising or setting, are elevated by refraction more than their whole diameter, so that they appear above the horizon both before they have actually risen and after they have set.

221. TWILIGHT *is that illumination of the sky which takes place before sunrise and after sunset,* by means of which the day advances and retires by a gradual increase or diminution of the light. While the sun is within eighteen degrees of the horizon, some portion

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219. What is horizontal parallax? What use is made of horizontal parallax?

220. Define refraction. How is a ray of light affected by traversing the atmosphere? How does refraction affect the apparent places of the heavenly bodies? What is said of the sun and moon?

of its light is conveyed to us by means of the numerous reflexions from the atmosphere. At the equator, where the circles of daily motion are perpendicular to the horizon, the sun descends through eighteen degrees in an hour and twelve minutes. In tropical countries, therefore, the light of day rapidly declines, and as rapidly advances after daybreak in the morning. At the pole, a constant twilight is enjoyed while the sun is within eighteen degrees of the horizon, occupying nearly two-thirds of the half year, when the direct light of the sun is withdrawn, so that the progress from continual day to constant night is exceedingly gradual. To an inhabitant of one of the temperate zones, the twilight is longer in proportion as the place is nearer the elevated pole.

CHAPTER IV.

THE SUN.

DISTANCE—MAGNITUDE—QUANTITY OF MATTER—SPOTS—NATURE AND CONSTITUTION—REVOLUTIONS—SEASONS.

222. THE *distance* of the sun from the earth is about ninety-five millions of miles. Although, by means of the sun's horizontal parallax, astronomers have been able to find this distance in a way that is entitled to the fullest confidence, yet such a distance as 95,000,000 of miles seems almost incredible. Still it is but small compared with the distance of the fixed stars. Let us make an effort to form some idea of this vast distance, which we shall do best by gradual approaches to it. We will then begin with so small a distance

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221. Define twilight. How far is the sun below the horizon when the twilight ceases? How is it at the equator—at the poles—and in the middle latitudes?

222. Distance of the sun from the earth. How does it compare with

as that across the Atlantic ocean, and follow in mind a ship, as she leaves the port of New York, and after twenty days' sail reaches Liverpool. Having formed the best idea we can of this distance, we may then reflect, that it would take a ship, moving constantly at the rate of ten miles an hour, more than a thousand years to reach the sun.

223. The *diameter* of the sun is toward a million of miles; or, more exactly, it is 885,000 miles. One hundred and twelve bodies as large as the earth, lying side by side, would be required to reach across the solar disk; and our ship, sailing at the same rate as before, would be ten years in passing over the same space. Immense as is the sun, we can readily understand why it appears no larger than it does, when we reflect that its distance is still more vast. Even large objects on the earth, when seen on a distant eminence, or over a wide expanse of waters, dwindle almost to a point. Could we approach nearer and nearer to the sun, it would constantly expand its volume until it finally filled the whole sky. We could, however, approach but little nearer the sun than we are, without being consumed by his heat. Whenever we come nearer to any fire, the heat rapidly increases, being four times as great at half the distance, and one hundred times as great at one tenth the distance. This fact is expressed by saying, that heat increases as the square of the distance decreases. Our globe is situated at such a distance from the sun, as exactly suits the animal and vegetable kingdoms. Were it either much nearer or more remote, they could not exist, constituted as they are. The intensity of the solar light also follows the same

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that of the fixed stars? Effort to form an idea of great distances. How long would it take a ship, moving ten miles an hour, to reach the sun?

223. Diameter of the sun. How many bodies like the earth would it take to reach across the sun? How long the ship to sail over it? Why it appears no larger? How would it appear could we approach nearer and nearer to it? How is the intensity of heat proportioned

law. Consequently, were we much nearer the sun than we are, its blaze would be insufferable; or were we much farther off, the light would be too dim to serve all the purposes of vision.

224. The sun is one million four hundred thousand (1,400,000) times as large as the earth; but its matter is only about one fourth as dense as that of the earth, being only a little heavier than water, while the average density of the earth is more than five times that of water. Still, on account of the immense magnitude of the sun, its *quantity of matter* is 354,000 times as great as that of the earth. Bodies would weigh about twenty-eight times as much at the surface of the sun as they do on the earth. Hence, a man weighing three hundred pounds would, if conveyed to the surface of the sun, weigh 8,400 pounds, or nearly three tons and three quarters. A man's limb, weighing forty pounds, would require to lift it a force of 1,120 pounds, which would be beyond the ordinary power of the muscles. At the surface of the earth, a body falls from rest by the force of gravity, in one second, $16\frac{1}{12}$ feet; but at the surface of the sun, a body would, in the same time, fall through 449 feet.

225. When we look at the sun through a telescope, we commonly find on his disk a greater or less number of dark places, called *Solar Spots*. Sometimes the sun's disk is quite free from spots, while at other times we may see a dozen or more distinct clusters, each containing a great number of spots, some large and some very minute. Occasionally a single spot is so large as to be visible to the naked eye, especially when

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to the distance? Were the earth nearer the sun, what would be the consequence? How would its light increase?

224. How much larger is the sun than the earth? How much greater is its quantity of matter? How much more would bodies weigh at the sun than at the earth? How much would a man of three hundred pounds weigh? Through what space would a body fall in a second?

225. Solar spots—their number—size of the largest—their apparent

the sun is near the horizon, and the glare of his light is taken off. Spots have been seen more than 50,000 miles in diameter. They move slowly across the central regions of the sun. As they have all a common motion from day to day across the sun's disk; as they go off on one limb, and, after a certain interval, sometimes come on again on the opposite limb, it is inferred that this apparent motion is imparted to them by an actual revolution of the sun on his axis, which is accomplished in about twenty-five days. This is called the sun's *diurnal* revolution, while his apparent movement about the earth once a year is called his *annual* revolution.

226. We have seen that the apparent revolution of the heavenly bodies, from east to west, every twenty-four hours, is owing to a real revolution of the earth on its own axis in the opposite direction. This motion is very easily understood, resembling, as it does, the spinning of a top. We must, however, conceive of the top as turning without any visible support, and not as resting in the usual manner on a plane. The annual motion of the earth around the sun, which gives rise to the apparent motion of the sun around the earth once a year, is somewhat more difficult to understand. When, as the string is pulled, the top is thrown forward on the floor, we may see it move onward (sometimes in a circle) at the same time that it spins on its axis. Let a candle be placed on a table, to represent the sun, and let these two motions be imagined to be given to a top around it, and we shall have a case somewhat resembling the actual motions of the earth around the sun.

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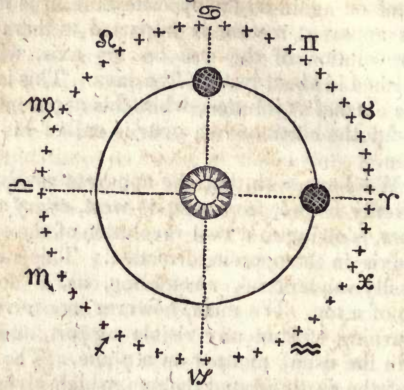
motions—revolution of the sun. Distinction between the diurnal and annual revolutions of the sun.

226. To what is the apparent daily motion of the sun from east to west owing? How to conceive of it? How to conceive of the annual motion?

227. When bodies are at such a distance from each other as the earth and sun, a spectator on either would project the other body upon the face of the sky, always seeing it on the opposite side of a great circle, one hundred and eighty degrees from himself. Let Fig. 102 represent the relative positions of the earth and sun, and the firmament of stars. A spectator on the earth at ♈, (Aries,) would see the sun in the heavens at ♎, (Libra ;) and while the earth was moving from ♈ to ♋, (Cancer,) not being conscious of our own motion, but observing the sun to shift his apparent place from ♎ to ♑, (Capricornus,) we should attribute the change to a real motion in the sun, and infer that the sun revolves about the earth once a year, and not the earth about the sun. Although astronomers have learned to correct this erroneous impression, yet they still, as a matter of convenience, speak of the sun's annual motion.

Fig. 102.



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227. How would a spectator on the sun or the earth, project the other body ? Illustrate by the Figure.

228. In endeavoring to obtain a clear idea of the revolution of the earth around the sun, imagine to yourself a plane (a geometrical plane, having merely length and breadth, but no thickness,) passing through the centers of the sun and earth, and extended far beyond the earth, until it reaches the firmament of stars. This is the *plane* of the ecliptic; the circle in which it seems to cut the heavens is the *celestial ecliptic ;* and the path described by the earth in its revolution around the sun, is the *earth's orbit.* This is to be conceived of as near to the sun compared with the celestial ecliptic, although both are in the same plane. Moreover, we *project* the sun into the celestial ecliptic, because it seems to travel along the face of the starry heavens, since the sun and stars are both so distant that we cannot distinguish between them in this respect, but see them both as if they were situated in the imaginary dome of the sky. If the sun left a visible trace on the face of the sky, the celestial ecliptic would of course be distinctly marked on the celestial sphere, as it is on an artificial globe ; and were the celestial equator delineated in a similar manner, we should then see, at a glance, the relative position of these two circles ; the points where they intersect one another constituting the *equinoxes ;* the points where they are at the greatest distance asunder, being the *solstices ;* and the angle which the two circles make with each other, (23° 28′,) being the *obliquity of the ecliptic.*

229. As the earth traverses every part of her orbit in the course of a year, she will be once at each solstice, and once at each equinox. The best way of

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228. To obtain a clear idea of the revolution of the earth around the sun, what device shall we employ ? What is the *plane* of the ecliptic ? What the celestial ecliptic ? What the earth's orbit ? Into what do we project the sun ? If the sun left a visible track, what would it mark out ? If the celestial equator were delineated in the same way, what would it mark out ? Where would be the equinoxes—the solstices ? What is the obliquity ?

obtaining a correct idea of her two motions, is to conceive of her as standing still a single day, at some point in her orbit, until she has turned once on her axis, then moving about a degree, and halting again until another diurnal revolution is completed. Let us suppose the earth at the Autumnal Equinox, the sun, of course, being at the Vernal Equinox. Suppose the earth to stand still in its orbit for twenty-four hours. The revolution of the earth on its axis, in this period, from west to east, will make the sun appear to describe a great circle of the heavens from east to west, coinciding with the equator. At the end of this time, suppose the sun to move northward one degree in its orbit, and to remain there twenty-four hours, in which time the revolution of the earth will make the sun appear to describe another circle from east to west, but a little north of the equator. Thus, we may conceive of the sun as moving one degree in the northern half of its orbit, every day, for about three months, when he will reach the point of the ecliptic farthest from the equator, which point is called the *tropic*, from a Greek word signifying *to turn;* because, after the sun has passed this point, his motion in his orbit carries him continually toward the equator, and therefore he seems to turn about. The same point is also called the *solstice*, from a Latin word signifying *to stand still;* since, when the sun has reached its greatest northern or southern limit, he seems for a short time stationary, with regard to his annual motion, appearing for several days to describe, in his daily motion, the same parallel of latitude.

230. When the sun is at the northern tropic, which happens about the 21st of June, his elevation above the southern horizon at noon is the greatest in the

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229. How to obtain a clear idea of the earth's two motions—describe the process—why is the turning point called the tropic? Why the solstice?

year; and when he is at the southern tropic, about the 21st of December, his elevation at noon is the least in the year.

231. The motion of the earth, in its orbit, is nearly seventy times as great as its greatest motion around its axis. In its revolutions around the sun, the earth moves no less than 1,640,000 miles a day, 68,000 miles an hour, 1,100 miles a minute, and 19 miles every second—a velocity sixty times as great as the greatest velocity of a cannon ball. Places on the earth turn with very different degrees of velocity in different latitudes. Those on the equator are carried round at the rate of about 1000 miles an hour. In our latitude, (41° 18′,) the diurnal velocity is about 750 miles an hour. It would seem at first quite incredible that we should be whirled round at so rapid a rate, and yet be entirely insensible of any motion; and much more that we should be going on so swiftly through space, in our circuit around the sun, while all things, when unaffected by local causes, appear to be in such a state of quiescence. Yet we have the most unquestionable evidence of the fact; nor is it difficult to account for it, in consistency with the general state of repose among bodies on the earth, when we reflect that their relative motions, with respect to each other, are not in the least disturbed by any motions which they may have in common. When we are on board a steamboat, we move about in the same manner when the boat is in rapid motion, as when it is lying still; and such would be the case, if it moved steadily a hundred times faster than it does. Were

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230. When does the sun reach the northern tropic? How is then his altitude? When is he at the southern tropic? His altitude then?

231. How much greater is the motion of the earth in its orbit than on its axis? How many miles per day—per hour—per minute—per second? Rates of motion of places in different latitudes? Rate in latitude 41 degrees and 18 minutes? Why are we insensible to this

the earth, however, suddenly to stop its *diurnal* motion, all movable bodies on its surface would be thrown off in tangents to the surface, with velocities proportional to that of their diurnal motion; and were the earth suddenly to halt in its *orbit*, we should be hurled forward into space with inconceivable rapidity.

232. The phenomena of the SEASONS, which we may now explain, depend on two causes; first, the inclination of the earth's axis to the plane of its orbit; and, secondly, to the circumstance that the earth's axis always remains parallel to itself. Imagine a candle, placed in the center of a large ring of wire, to represent the sun in the center of the earth's orbit, and an apple with a knitting-needle running through it, in the direction of the stem. Run a knife round the central part of the apple, to mark the situation of the equator. The circumference of the ring represents the earth's orbit in the plane of the ecliptic. Place the apple so that the equator shall coincide with the wire; then the axis will lie directly across the plane of the ecliptic; that is, at right angles to it. Let the apple be carried quite round the ring, constantly preserving the axis parallel to itself, and the equator all the while coinciding with the wire that represents the orbit. Now, since the sun enlightens half the globe at once, so the candle, which here represents the sun, will shine on the half of the apple that is turned toward it; and the circle which divides the enlightened from the unenlightened side of the apple, called the *terminator,* will pass through both the poles. If the apple be turned slowly round on its axis, the terminator will pass successively over all places on the earth, giving

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great motion? Illustrate by a steamboat. What would be the consequence were the earth suddenly to stop its motions?

232. What are the two causes of the change of seasons? How illustrated? How will the appearances be when the apple is so placed that its equator coincides with the wire? Where will it be sunrise—where sunset?

the appearance of sunrise to places at which it arrives, and of sunset to places from which it departs.

233. If, therefore, the earth's axis had been perpendicular to the plane of its orbit, in which case the equator would have coincided with the ecliptic, the diurnal motion of the sun would always have been in the equator, and the days and nights would have been equal all over the globe, and there would have been no change of seasons. To the inhabitants of the equatorial regions, the sun would always have appeared to move in the prime vertical, rising directly in the east, passing through the zenith at noon, and setting in the west. In the polar regions, the sun would always have appeared to revolve in the horizon; while, at any place between the equator and the pole, the course of the sun would have been oblique to the horizon, but always oblique in the same degree. There would have been nothing of those agreeable vicissitudes of the seasons which we now enjoy; but some regions of the earth would have been crowned with perpetual spring; others would have been scorched with a burning sun continually overhead; while extensive regions toward either pole, would have been consigned to everlasting frost and barrenness.

234. In order to simplify the subject, we have just supposed the earth's axis to be perpendicular to the plane of its orbit, making the equator to coincide with the ecliptic; but now, (using the same apparatus as before,) turn the apple out of a perpendicular position a little, (23½ degrees,) then the equator will be turned just the same number of degrees out of a coincidence with the ecliptic. Let the apple be carried around the

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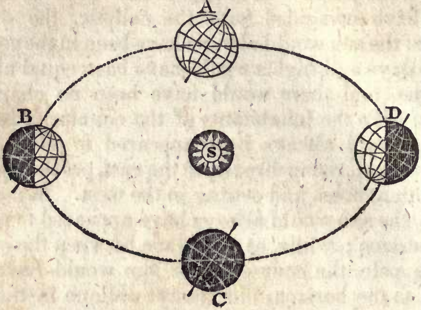
233. Comparative lengths of the days and nights? Appearances to the inhabitants of the equatorial regions? Of the polar regions? Would there have been any change of seasons?

234. Repeat the process with the axis inclined. How far would the equator be turned out of a coincidence with the ecliptic? How

ring, always holding it inclined at the same angle to the plane of the ring, and always parallel to itself, as

Fig. 103.



in figure 103. We shall find that there are two points, A and C, in the circuit, where the light of the sun (which always enlightens half the globe at once) reaches both poles. These are the points where the celestial equator and ecliptic cut one another, or the equinoxes. When the earth is at either of these points, the sun shines on both poles alike; and if we conceive of the earth, while in this situation, as turning once round on its axis, the apparent diurnal motion of the sun would be the same as it would be, were the earth's axis perpendicular to the plane of the equator. For that day, the earth would appear to revolve in the equator, and the days and nights would be equal all over the globe.

235. If the apple were carried round in the manner supposed, then, at the distance of ninety degrees from the equinoxes, at B and D, the same pole would be turned toward the sun on one side, just as much as it

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does the sun then shine with respect to the poles? What will then be the appearances in the diurnal motion?

was turned from him on the other. In the former case, the sun's light would reach beyond the pole 23½ degrees, and in the other case, it would fall short of it the same number of degrees. Now imagine, again, the earth turning in the daily revolution, and it will be readily seen how places within 23½ degrees of the enlightened pole, will have continual day, while places within the same distance of the unenlightened pole, will have continual night. By an attentive inspection of figure 103, all these things will be clearly understood. The earth's axis is represented as prolonged, both to show its position, and to indicate that it always remains parallel to itself. On March 21st and September 22d, when the earth is at the equinoxes, the sun shines on both poles alike; while on June 21st and December 24th, when the earth is at the solstices, the sun shines 23½ degrees beyond one pole, and falls the same distance short of the other.

236. Two causes contribute to increase the heat of summer and the cold of winter,—*the changes in the sun's meridian altitudes, and in the lengths of the days.* The higher the sun ascends above the horizon, the more directly his rays fall upon the earth; and their heating power is rapidly increased as they approach a perpendicular direction. The increased length of the day in summer, affects greatly the temperature of places toward the poles, because the inequality between the lengths of the day and night is greater in proportion as we recede from the equator. By the operation of this cause, the heat accumulates so much in summer, that the temperature rises to a higher degree in midsummer, at places far removed from the equator, than within the torrid zone.

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235 At the distance of 90 degrees from the equinoxes, how would the sun shine with respect to the poles?

236 What two causes contribute to increase the heat of summer and the cold of winter? Effect of the sun's altitude—of the increased length of the day?

237. But the temperature of a place is influenced very much by several other causes, as well as by the force and duration of the sun's heat. First, the *elevation* of a country above the level of the sea, has a great influence upon its climate. Elevated districts of country, even in the torrid zone, often enjoy the most agreeable climate in the world. The cold of the upper regions of the atmosphere modifies and tempers the solar heat, so as to give a most delightful softness, while the uniformity of temperature excludes those sudden and excessive changes which are often experienced in less favored climes. In ascending high mountains, situated within the torrid zone, the traveller passes, in a short time, through every variety of climate, from the most oppressive and sultry heat, to the soft and balmy air of spring, which again is succeeded by the cooler breezes of autumn, and then by the severest frosts of winter. A corresponding difference is seen in the products of the vegetable kingdom. While winter reigns on the summit of the mountain, its central regions may be encircled with the verdure of spring, and its base with the flowers and fruits of summer. Secondly, the vicinity of the *ocean* has also a great effect to equalize the temperature of a place. As the ocean changes its temperature during the year much less than the land, it becomes a source of warmth to neighboring countries in winter, and a fountain of cool breezes in summer. Thirdly, the relative *moisture* or *dryness* of the atmosphere of a place is of great importance, in regard to its effects on the human system. A dry air, of ninety degrees, is not so insupportable as a moist air of eighty degrees. As a general principle, a hot and moist air is unhealthy, although a hot air, when dry, may be very salubrious.

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237. Effect of elevation—of the vicinity of the ocean—relative moisture and dryness.

CHAPTER V.

THE MOON.

DISTANCE AND DIAMETER—APPEARANCES TO THE TELESCOPE—MOUNTAINS AND VALLEYS—REVOLUTION—ECLIPSES—TIDES.

238. THE Moon is a constant attendant or satellite of the earth, revolving around it at the distance of about 240,000 miles. Her diameter exceeds 2,000 miles, (2160.) Her *angular* breadth is about half a degree,—a measure which ought to be remembered, as it is common to estimate fire-balls, and other sights in the sky, by comparing them with the size of the moon. The sun's angular diameter is a little greater.

239. When we view the moon through a good telescope, the inequalities of her surface appear much more conspicuous than to the naked eye; and by studying them attentively, we see undoubted proofs that the face of the moon is very rough and broken, exhibiting high mountains and deep valleys, and long mountainous ridges. The line which separates the enlightened from the dark part of the moon, is called the *Terminator*. This line appears exceedingly *jagged*, indicating that it passes over a very broken surface of mountains and valleys. Mountains are also indicated by the *bright points* and crooked lines, which lie beyond the terminator, within the unilluminated part of the moon; for these can be nothing else than elevations above the general level, which are enlightened by the sun sooner than the surrounding countries, as high mountains on the earth are tipped with the morning light sooner than the countries at their bases. Moreover, when these pass the terminator, and come

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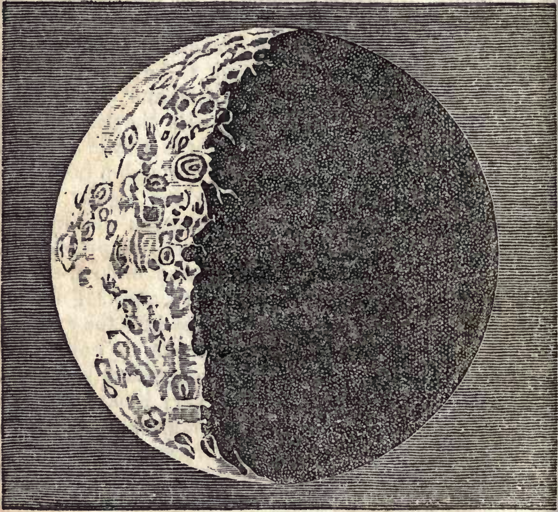
238. Of what is the moon a satellite? Distance frcm the earth—diameter—angular breadth. Why is it important to remember this?

239 How does the moon appear to the telescope? What is the Terminator? How does it appear? What does its unevenness indicate? What signs of mountains are there in the dark part of the

within the enlightened part of the disk, they are further recognised as mountains, because they cast shadows opposite the sun, which vary in length as the sun strikes them more or less on a level.

Fig. 104.



240. Spots, also, on the lunar disk, are known to be valleys, because they exhibit the same appearance as is seen when the sun shines into a tea cup, when it strikes it very obliquely. The inside of the cup, opposite to the sun, is illuminated in the form of a crescent,

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moon? When the terminator passes beyond these, what signs of being mountains do they give?

240. Valleys, how known. Illustrate by the mode in which light

(as every one may see, who will take the trouble to try the experiment,) while the inside, next the sun, casts a deep shadow. Also, if the cup stands on a table, the side farthest from the sun casts a shadow on the table outside of the cup. Similar appearances, presented by certain spots in the moon, indicate very clearly that they are valleys. Many of them are regular circles, and not unfrequently we may see a chain of mountains, surrounding a level plain of great extent, from the center of which rises a sharp mountain, casting its shadow on the plain within the circle. Figure 104 is an accurate representation of the telescopic appearance of the moon when five days old. It will be seen that the terminator is very uneven, and that white points and lines within the unenlightened part of the disk, indicate the tops of mountains and mountain ridges. Near the bottom of the terminator, a little to the left, we see a small circular spot, surrounded by a high chain of mountains, (as is indicated by the shadows they cast,) and in the center of the valley the long shadow of a single mountain thrown upon the plain. Just above this valley, we see a ridge of mountains, casting uneven shadows opposite to the sun, some sharp, like the shadows of mountain peaks. These appearances are, indeed, rather minute; but we must recollect that they are represented on a very small scale. The most favorable time for viewing the mountains and valleys of the moon with a telescope, is when she is about seven days old.

241. The full moon does not exhibit the broken aspect so well as the new moon; but we see dark and light regions intermingled. The dusky places in the moon were formerly supposed to consist of water, and

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shines into a cup. What shape have many of the valleys? What do we sometimes see surrounding the valley? What rising in the center of it? Point out mountains and valleys on the diagram.

241. What is said of the telescopic view of the full moon? What

the brighter places, of land; astronomers, however, are now of the opinion, that there is no water in the moon, but that the dusky parts are extensive plains, while the brightest streaks are mountain ridges. Each separate place has a distinct name. Thus, a remarkable spot near the top of the moon, is called Tycho; another, Kepler; and another, Copernicus; after celebrated astronomers of these names. The large dusky parts are called seas, as the Sea of Humors, the Sea of Clouds, and the Sea of Storms. Some of the mountains are estimated as high as five miles, and some of the valleys four miles deep.

242. The moon revolves about the earth from west to east, once a month, and accompanies the earth around the sun once a year. The interval in which she goes through the entire circuit of the heavens, from any star round to the same star again, is called a *sidereal* month, and consists of about 27¼ days; but the time which intervenes between one new moon and another, is called a *synodical* month, and is composed of 29½ days. A new moon occurs when the sun and moon meet in the same part of the heavens; for although the sun is 400 times as distant from us as the moon, yet as we project them both upon the face of the sky, the moon seems to be pursuing her path among the stars as well as the sun. Now the sun, as well as the moon, is travelling eastward, but with a slower pace; the sun moves only about a degree a day, while the moon moves more than thirteen degrees a day. While the moon, after being with the sun, has been going round the earth in 27¼ days, the sun, mean-

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were the dark places in the moon formerly supposed to be? What do astronomers now consider them? How are places on the moon named? Repeat some of the names. What is the height of some of the mountains, and depth of the valleys?

242 Revolutions of the moon. What is a sidereal month? How long is it? What is a synodical month? When does a new moon occur? Why is the synodical longer than the sidereal month?

while, has been going eastward about 27 degrees; so that, when the moon returns to the part of the heavens where she left the sun, she does not find him there, but takes more than two days to catch up with him.

243. The moon, however, does not pursue precisely the same track with the sun in his apparent annual motion, though she deviates but little from his path. The inclination of her orbit to the ecliptic is only about five degrees, and, of course, the moon is never seen farther from the ecliptic than that distance, and she is commonly much nearer to it than that. The two points where the moon's orbit crosses the ecliptic, are called her *nodes*. They are the intersections of the solar and lunar orbits, as the equinoxes are the intersections of the equator and ecliptic, and, like the latter, are 180 degrees apart.

Fig. 105.

244. The changes of the moon, commonly called her *phases*, arise from different portions of her enlightened side being turned toward the earth at different times. When the moon comes between the earth and the sun, her dark side is turned toward us, and we lose sight of her for a short period, at A, (Fig. 105,) when she is said to be in *conjunction*. As soon as she gets a little past conjunction, at B, we first observe her in the evening sky, in the form of a crescent,—the well known appearance of the new moon. When at C, half her enlightened disk is turned toward us, and she is in *quadrature*, or in her first quarter.

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243. How many degrees is the moon's orbit inclined to the ecliptic? Define the nodes. How far apart?

244. Whence arise the phases of the moon? When is the moon said to be in conjunction? When in quadrature? When in oppo-

At D, three-fourths of the disk is illuminated, and at E, when the earth lies between the sun and the moon, her whole disk is enlightened, and she is in *opposition*, the time of full moon. In proceeding from opposition to conjunction, or from full to new moon, the illuminated portion diminishes in the same way as it increased from conjunction to opposition, being in the last quarter, at G. Within the first and last quarters, the terminator is turned from the sun, and the moon is said to be *horned;* but within the second and third quarters, the terminator presents its concave side toward the sun, and the moon is said to be *gibbous*.

245. The moon *turns on her axis* in the same time in which she revolves about the earth. This is known by the moon's always keeping nearly the same face toward us, as is indicated by the telescope, which could not be the case, unless her revolution on her axis kept pace with her motion in her orbit. Take an apple to represent the moon: thrust a knitting-needle through it in the direction of the stem, to represent the axis, in which case the two eyes of the apple will naturally represent the poles. Through the poles, cut a line around the apple, dividing it into two hemispheres, and mark them so as to be readily distinguished from each other. Now place a ball on the table to represent the earth, and holding the apple by the knitting-needle, carry it round the ball, and it will be seen that, unless the apple is made to turn about on its axis, as it is carried around the ball, it will present different sides toward the ball; and that, in order to make it always present the same side, it will be necessary to make it revolve exactly once on its axis, while it is

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sition? What figure has the moon in the first and last quarters? What in the second and third?

245. In what time does the moon turn on her axis? How is this known? How illustrated by an apple with a knitting-needle? By walking round a tree?

going round the circle,—the revolution on its axis keeping exact pace with the motion in its orbit. The same thing will be observed, if we walk around a tree, always keeping the face toward the tree. It will be necessary to turn round on the heel at the same rate as we go forward round the tree.

246. An *Eclipse of the Moon* happens when the moon, in its revolution around the earth, falls into the earth's shadow. An *Eclipse of the Sun* happens when the moon, coming between the earth and the sun, covers either a part or the whole of the solar disk. As the direction of the earth's shadow is, of course, opposite to the sun, the moon can fall into it only when in opposition, or at the time of full moon; and as the moon can come between us and the sun only when in conjunction, or at the time of new moon, it is only then that a solar eclipse can take place. If the moon's orbit lay in the plane of the ecliptic, we should have a solar eclipse at every new moon, and a lunar eclipse at every full moon; but as the moon's orbit is inclined to the plane of the ecliptic about five degrees, the moon may pass by the sun on one side, and the earth's shadow on the other side, without touching either. It is only when, at new moon, the sun happens to be at or near the point where the lunar orbit cuts the plane of the ecliptic, or at one of the *nodes*, that the moon's disk overlaps the sun's, and produces a solar eclipse. Also, when the sun is at or near one of the moon's nodes, the earth's shadow is thrown across the other node, on the opposite side of the heavens, and then, as the moon passes through this node, at the time of opposition, she falls within the shadow, and produces a lunar eclipse.

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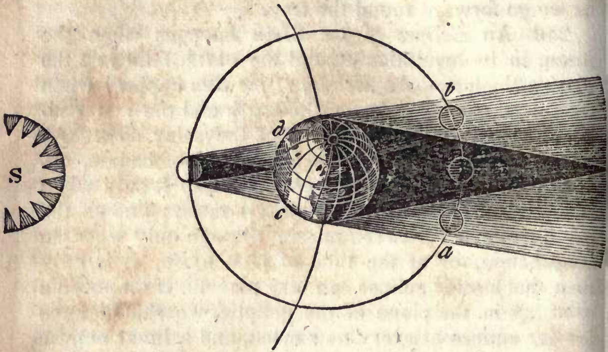
246. When does an eclipse of the moon happen? When an eclipse of the sun? At what age of the moon does it eclipse the sun—and at what age does it suffer eclipse? Why do not eclipses occur at every revolution? At or near what point must the sun be, in order that an eclipse may take place?

247. Figure 106 represents both kinds of eclipses. The shadow of the moon, when in conjunction, is represented as just long enough to reach the earth, as

Fig. 106.



is the case when the moon is at or about her average distance from the earth. In this case, a spectator on the earth, situated at the place where the point of the shadow touches the earth, would see the sun totally eclipsed for an instant, while the countries around, for a considerable distance, would see only a partial eclipse, the moon hiding only a part of the sun, which sheds on such places a partial light, called the *penumbra,* as is indicated in the figure by the dark shading on each side of the moon's shadow. A similar penumbra is represented on each side of the earth's shadow, because, when the moon is approaching the shadow, a part of the light of the sun begins to be intercepted from her when she reaches this limit, and

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247. Describe Fig. 106. At what point of the earth would the eclipse of the sun be total? Where partial? What is this partial light called? What is said of the moon's penumbra? What occasions an annular eclipse?

she receives less and less of light from the sun, until, when she enters the shadow, his disk is entirely hidden. When the moon is farther from the earth than her average distance, her disk is not large enough to cover the sun's, but a ring of the sun appears all around the moon, constituting an *annular* eclipse.

248. Eclipses of the sun are more frequent than those of the moon. Yet, lunar eclipses, being visible to every part of the hemisphere of the earth in which the moon is above the horizon, while those of the sun are visible only to a small portion of the hemisphere on which the moon's shadow falls, it happens that, for any particular place on the earth, there are seen more eclipses of the moon than of the sun. In any year, the number of eclipses of both luminaries cannot be less than two, nor more than seven. The most usual number is four, and it is very rare to have more than six. A total eclipse of the moon frequently happens at the next full moon after an eclipse of the sun. For, since, in a solar eclipse, the sun is at or near one of the moon's nodes,—that is, is projected to the place in the sky where the moon crosses the ecliptic,—the earth's shadow, which is, of course, directly opposite to the sun, must be at or near the other node, and may not have passed too far from the node before the moon comes round to the opposition and overtakes it.

249. A total eclipse of the sun is one of the most sublime and impressive phenomena of Nature. Among barbarous tribes, it is always looked on with fear and astonishment, and as strongly indicative of the wrath of the gods. When Columbus first discovered America,

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248. Which are most frequent, the eclipses of the sun or the moon? Of which are the greatest number visible? What number of both can happen in a single year? What is the most usual number? Why does an eclipse of the moon happen at the next full moon after an eclipse of the sun?

249. What is said of an eclipse of the sun? What is told of Columbus? Why is a total eclipse of the sun regarded with so

and was in danger of hostility from the natives, he awed them into submission by telling them that the sun would be darkened on a certain day, in token of the anger of the gods at them for their treatment of him. Among cultivated nations, also, a total eclipse of the sun is regarded with great interest, as verifying with astonishing exactness the predictions of astronomers, and evincing the great knowledge they have acquired of the motions of the heavenly bodies, and of the laws by which they are governed. From 1831 to 1838, was a period distinguished for great eclipses of the sun, in which time there were no less than five, of the most remarkable character. The next total eclipse of the sun, visible in the United States, will occur on the 7th of August, 1869.

250. Since *Tides* are occasioned by the influence of the sun and moon, a few remarks upon them will conclude the present chapter. By the tides are meant the alternate rising and falling of the waters of the ocean. Its greatest and least elevations are called *high and low water;* its rising and falling are called *flood and ebb;* and the extraordinary high and low tides that occur twice every month, are called *spring* and *neap* tides. It is high water, or low water, on opposite sides of the globe at the same time. If, for example, we have high water at noon, it is also high water to those who live on the meridian below us, where it is midnight. In like manner, low water occurs at the same time on the upper and lower meridian. The average height of the tides, for the whole globe, is about two and a half feet; but their actual height at different places is very various, sometimes being scarcely perceptible, and

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much interest among cultivated nations? What period was distinguished for great eclipses of the sun? When will the next total eclipse of the sun occur?

250. What are the tides? What is meant by high and low water—flood and ebb—spring and neap? Where is it high water and

sometimes rising to sixty or seventy feet. In the Bay of Fundy, where the tide rises 70 feet, it comes in a mighty wave, seen thirty miles off, and roaring with a loud noise.

251. Tides are caused by the unequal attraction of the sun and moon upon different parts of the earth. We shall attend hereafter more particularly to the subject of universal gravitation, by which all bodies, or masses of matter, attract all other bodies, each according to its weight, when they act on a body at the same distance; but when at different distances, the force increases rapidly as the distance is diminished, so that the force of attraction is four times as great for half the distance, one hundred times as great for one tenth the distance, and, universally, the force increases in proportion as the square of the distance diminishes. Such a force as this is exerted by the moon and by the sun upon the earth, and causes the tides. As the sun has vastly more matter than the moon, it would raise a higher tide than the moon, were it not so much farther off. This latter circumstance gives the advantage to the moon, which has three times as much influence as the sun in raising the tides. If these bodies, one or both of them, acted *equally* on all parts of the earth, they would draw all parts toward them alike, but would not at all disturb the mutual relation of the parts to each other, and, of course, would raise no tide. But the sun or moon attracts the water on the side nearest to it more than the water more remote, and thus raises them above the general level, forming the *tide wave*, which accompanies the moon in her daily revolution around the earth. It is not difficult to see how the tide is thus raised on the

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where low water at the same time? Average height of the tides for the whole globe. What is said of their actual height at different places? How high does the tide rise in the Bay of Fundy?

251. By what are tides caused? What force is exerted by the sun and moon upon the earth? Why does not the sun raise a greater tide than the moon? How does the sun's greater distance give the

side of the meridian nearest to the moon; but it may not be so clear why a tide should at the same time be raised on the opposite meridian. The reason of this is, that the waters farthest from the moon, being attracted less than those that are nearer, and less than the solid earth, are *left behind*, or appear to rise in a direction opposite to the center of the earth. Hence, we have two tides every twenty-four hours,—one when the moon passes the upper meridian, and one when she passes the lower. Each, however, is about fifty minutes later to-day than yesterday, for the moon comes to the meridian so much later on each following day.

252. Were it not for the impediments which prevent the force from producing its full effects, we might expect to see the great tide wave always directly beneath the moon, attending it regularly around the globe. But the inertia of the waters prevents their instantly obeying the moon's attraction, and the friction of the waters on the bottom of the ocean still further retards its progress. It is not, therefore, until several hours after the moon has passed the meridian of a place, that it is high tide at that place.

253. The sun has an action similar to that of the moon, but only *one third* as great. It is not that the moon actually exerts a greater force of attraction upon the earth than the sun does, that her influence in raising the tides exceeds that of the sun. She, in fact, exerts much less force. But, being so near, the *difference* of her attraction on different parts of the earth is greater than the difference of the sun's attraction; for the sun is so far off, that the diameter of the earth

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advantage to the moon? Why is it high tide on opposite sides of the earth at the same time? How much later is the high tide of to-day than that of yesterday?

252. Why is it not high tide when the moon is on the meridian?

253. How much less is the action of the sun in raising the tides than that of the moon? Why has the moon so much greater power?

bears but a small proportion to the distance, and therefore the force exerted by the sun is more nearly equal on all parts of the earth, and we must bear in mind that the tides are owing, not to the amount of the force of attraction, but to the difference of the forces exerted on different parts of the earth.

254. As the sun and moon both contribute to raise the tides, and as they sometimes act together and sometimes in opposition to each other, so corresponding variations occur in the height of the tides. The *spring tides*, or those which rise to an unusual height twice a month, are produced by the sun and moon's acting together; and the *neap tides*, or those which are unusually low twice a month, are produced by the sun and moon's acting in opposition to each other. The spring tides occur when the sun and moon act in the same line, as is the case both at new and full moon; and the neap tides when the two luminaries act in directions at right angles to each other, as is the

Fig. 107.

Fig. 108.

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254. Explain the spring tides—also the neap tides. Illustrate by the figures.

case when the moon is in quadrature. The mode of action, in each case, will be clearly understood by inspecting Figs. 107 and 108.

Fig. 107 shows the situation of the two luminaries when they act together at new moon. The waters are elevated both on the same side of the earth as the attracting bodies at A, and also on the opposite side, at B. If we now conceive the moon to change its place to B, when it would be full moon, the waters would still have the same elongated figure in the line of the two bodies, while at places 90° distant, at C and D, it would be low water. Again, in Fig. 108, the moon being in quadrature at C, the two attracting bodies act in opposition to each other, the sun raising a tide at A and B, while the moon raises a still higher tide at C and D. Hence, the high tide beneath the moon, and the low tide at places 90° distant, are both less than ordinary.

255. The largest lakes and inland seas have no perceptible tides. This is asserted by all writers respecting the Caspian and Black seas; and the same is found to be true of the largest of the North American lakes, Lake Superior. Although these several tracts of water appear large, when taken by themselves, yet they occupy but small portions of the surface of the globe, as will be evident on seeing how small a space they occupy on the artificial globe; so that the attraction of the sun and moon is nearly equal on all parts of such sea or lake. But it is the *inequality* of attraction on different parts that produces the tides.

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255. Why have lakes and inland seas no tides?

CHAPTER VI.

THE PLANETS.

GENERAL VIEW—INFERIOR PLANETS—SUPERIOR PLANETS—PLANETARY MOTIONS.

SECTION 1. *General View of the Planets.*

256. THE name planet is derived from a Greek word which signifies a *wanderer*, and is applied to this class of bodies, because they shift their positions in the heavens, whereas the fixed stars constantly maintain the same places with respect to each other. The planets known from a high antiquity are, Mercury, Venus, Earth, Mars, Jupiter, and Saturn. To these, in 1781, was added Uranus, (or Herschel, as it is sometimes called, from the name of the discoverer.) and, as late as the commencement of the present century, four more were added, namely, Ceres, Pallas, Juno, and Vesta. All these are called *primary* planets. Several of them have one or more attendants, or *satellites*, which revolve around them, as they revolve around the sun. The Earth has one satellite, namely, the Moon; Jupiter has four, Saturn seven, and Uranus six. Mercury, Venus, and Mars, are without satellites. The same is the case with the four new planets, or *asteroids*, as they are sometimes called. The whole number of planets, therefore, is twenty-nine, namely, eleven primary, and eighteen secondary planets.

257. Mercury and Venus are called *inferior* planets, because they have their orbits nearer to the sun than that of the earth; while all the others, being more distant from the sun than the earth is, are called *superior*

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256. Whence the name planet? What planets have been known from a high antiquity? What have been added to these? What is said of the satellites? What is the whole number of planets?

257. Why are Mercury and Venus called inferior planets? Why the others superior planets?

planets. Let us now compare the planets with one another, in regard to their distances from the sun, their magnitudes, and their times of revolution.

258. *Distances from the sun, in miles.*

1. Mercury,	☿	37,000,000.
2. Venus,	♀	68,000,000.
3. Earth,	⊕	95,000,000.
4. Mars,	♂	142,000,000.
5. Vesta,	⚶	225,000,000.
6. Juno,	⚵	261,000,000.
7. Ceres,	⚳	
8. Pallas,	⚴	
9. Jupiter,	♃	485,000,000.
10. Saturn,	♄	490,000,000.
11. Uranus,	♅	1800,000,000.

The dimensions of the planetary system are seen from this table to be vast, comprehending a circular space thirty-six hundred millions of miles in diameter. A railway car, travelling constantly at the rate of twenty miles an hour, would require more than twenty thousand years to cross the orbit of Uranus.

259. *Magnitudes.*

	Diameter.		Diameter.
1. Mercury,	3140.	5. Ceres,	160
2. Venus,	7700.	6. Jupiter,	89,000
3. Earth,	7912.	7. Saturn,	79,000
4. Mars,	4200.	8. Uranus,	35,000

We perceive that there is a great diversity among the planets, in regard to size. While Venus, an *inferior* planet, is nine-tenths as large as the Earth, Mars, a *superior* planet, is only one-seventh, while Jupiter is twelve hundred and eighty-one times as large.*

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* The magnitudes are proportioned to the *cubes* of the diameters.

258. Repeat the table of distances. What is said of the dimensions of the planetary system? How long would a railway car be in crossing the orbit of Uranus?

259. Repeat the table of magnitudes. What is said of the diversity

Although several of the planets, when nearest to us, appear brilliant and large when compared with most of the fixed stars, yet the angle under which they are seen is very small, that of Venus, the greatest of all, never exceeding about one minute, which is less than one thirtieth the apparent diameter of the sun or moon.* Jupiter, also, by his superior brightness, sometimes makes a striking figure among the stars; yet his greatest apparent diameter is less than one fortieth that of the sun.

260. *Periodic Times.*

Mercury,	3 months.	Ceres,	$4\frac{2}{3}$ years.
Venus,	$7\frac{1}{2}$ "	Jupiter,	12 "
Earth,	1 year.	Saturn,	29 "
Mars,	2 years.	Uranus,	84 "

We perceive that the planets nearest the sun move most rapidly. Mercury performs nearly three hundred and fifty revolutions while Uranus performs one. The apparent progress of the most distant planets around the sun is exceedingly slow. Uranus advances only a little more than four degrees in a whole year; so that we find this planet occupying the same sign, and of course remaining nearly in the same part of the heavens, for several years in succession.

SEC. 2. *Of the Inferior Planets.*

261. Mercury and Venus have their orbits so far within that of the earth, that they appear to us as attendants upon the sun. Both planets appear either in the west a little after sunset, or in the east a little

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* In every estimation of angular breadths or distances, it is convenient to bear in mind that the angular breadth of the sun or moon is about half a degree.

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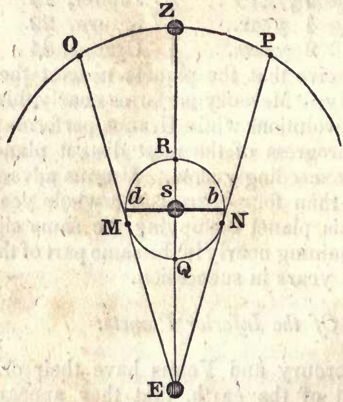
in regard to size? What of the angular diameter of the planets? How do the largest compare with the sun or moon?

260. Repeat the table of periodic times. What is said of the planets nearest the sun? What of those most distant?

261. How do Mercury and Venus appear with respect to the sun?

before sunrise. In high latitudes, where the twilight is long, Mercury can seldom be seen with the naked eye, and then only when its angular distance from the sun is greatest. In our latitude, we can usually catch a glimpse of this planet for several evenings and mornings, if we will watch the time (usually given in the almanac) when it is at its greatest elongations from the sun. It, however, soon runs back again to the sun. The reason of this will be plain from the following diagram. Let S represent the sun, E the earth,

Fig. 109.



M Q N R the orbit of Mercury, O Z P an arc of the heavens. Then, since we refer all distant bodies in the sky to the same concave sphere, we should see the sun at Z, in the heavens, and when the planet was at R or Q, we should see it close by the sun, and when it was

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What of Mercury in high latitudes? What in our latitude? When do we catch a glimpse of it? Explain the reason of this from the figure.

at its greatest elongation, at M or N, we should see it at O or P, when its angular distance from the sun would be measured by the arc O Z or P Z. Suppose Mercury comes into view at M, its greatest eastern elongation; as it passes on to Q, its inferior conjunction, it appears to move in the sky backward, or contrary to the order of the signs, from O to Z; and it continues its backward motion from M to N, or apparently from O to P. But now from N, its greatest western elongation, through R, its superior conjunction, to M, its greatest eastern elongation, its apparent motion is direct. Then, the planet is said to be in its *superior conjunction.* The inferior planets, Mercury and Venus, appear to run backward and forward across the sun, Mercury receding so little from that luminary as almost always to be lost in his beams. Venus, however, moves in a larger orbit, and recedes so far from the sun, on both sides, as often to remain a long time in the evening or morning sky, always immediately following or preceding the sun, and hence called the evening and morning star.

262. When an inferior planet is near its greatest elongation, on either side, it presents to us, when viewed with the telescope, half its enlightened disk, appearing to the telescope like the moon in one of her quarters. While passing from the eastern to the western elongation, through the inferior conjunction, the enlightened portion grows less and less, taking the crescent form, like the old of the moon, until it arrives at the inferior conjunction, when it presents the entire dark side toward us. Soon after passing the conjunction, it appears like the new moon, and increases to the first quarter, at the greatest western elongation. When passing through the superior conjunction, the other side

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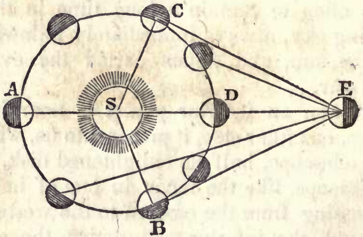
262. How does an inferior planet appear when at its greatest elongation? How when between that and the inferior conjunction? How toward the superior conjunction? In what respects do they

of the sun, the enlightened part constantly increases, and becomes like the full moon in the superior conjunction, after which the enlightened portion decreases. The phases of Mercury and Venus, therefore, as seen in the telescope, resemble the changes of the moon. In some respects, however, the appearances do not correspond to those of the moon; for since, when full, they are in the part of the orbit most remote from us, they appear then much smaller than when on the side of the inferior conjunction; and their nearness to the sun, when full, also prevents their being seen except in the day time, and then they are invisible to the naked eye, because their light is lost in that of the sun. Hence, these planets appear brightest when a little less than half their enlightened sides are turned toward us, (being then just within their greatest elongation on either side,) since their greater nearness to us more than compensates for having in view a less portion of the enlightened disk, as will be seen by the accompanying diagram.

Fig. 110.



263. Mercury and Venus both revolve on their axes in nearly the same time with the earth, and have therefore similar days and nights. Mercury owes

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resemble the changes of the moon? How do they differ? At what point do the inferior planets appear brightest?

almost all its peculiarities to its nearness to the sun. Its light and heat derived from the sun are estimated to be nearly seven times as great as ours, and the sun would appear to an inhabitant of Mercury seven times as large as it does to us. The motion of Mercury, in his revolution round the sun, is swifter than that of any other planet, being more than 100,000 miles every hour; whereas, that of the Earth is less than 70,000. Eighteen hundred miles every minute—crossing the Atlantic ocean in less than two minutes—this is a velocity of which we can form but very inadequate conceptions.

264. Every time Mercury and Venus come to their inferior conjunction, they would eclipse the sun, if their orbits coincided with the earth's orbit, or both were in the same plane; as we should have a solar eclipse at every new moon, if the moon's orbit were in the same plane with the earth's. As, however, the orbits of these planets are inclined to the ecliptic, they are not seen on the sun's disk except when the conjunction takes place at one of their nodes. They then pass over the sun, each in a round black spot, and the phenomenon is called a *Transit*. Transits of Mercury and Venus occur but seldom, but are regarded with the highest interest by astronomers, that of Venus, in particular; for, by observing it at distant points on the earth, materials are obtained for finding the sun's horizontal parallax, which enables astronomers to calculate the distance of the sun from the earth. (See Art. 219.) In the transits of Venus, in 1761 and 1769, several European governments fitted out expensive expeditions to parts of the earth remote from each other. For this purpose, the celebrated

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263. In what time do Mercury and Venus revolve on their axes? To what does Mercury owe its peculiarities? Explain his swiftness of motion.

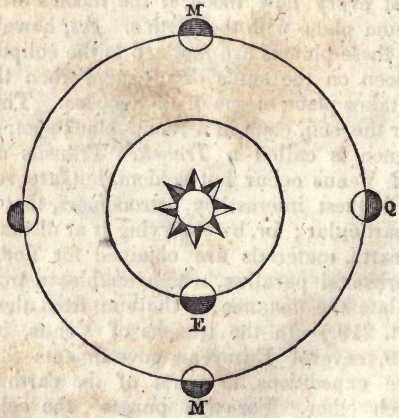
264. Why do not Mercury and Venus eclipse the sun at every inferior conjunction? What is a transit? Why regarded with so great

Captain Cook, in 1769, went to the South Pacific Ocean, and observed the transit of Venus at the island of Otaheite, (Tahiti,) while others went to Lapland for the same purpose, and others, still, to many other parts of the globe. The next transit of Venus will happen in 1874.

SEC. 3. *Of the Superior Planets.*

265. All the planets, except Mercury and Venus, have their orbits farther from the sun than the earth's orbit. They are seen in superior conjunction with the sun, and in opposition, like the moon when full; but as they are always more distant from the sun than the earth is, they can never come into inferior conjunction. This will be plain from the foregoing dia-

Fig. 111.



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interest? What is said of the transits of Venus in 1761 and 1769? When will the next transit of Venus happen?

gram. Let the Earth be at E, and a superior planet, as Mars, in different parts of his orbit, M Q M′. At M′, the planet would be seen in the same part of the heavens with the sun, rising and setting at the same time with him, and would therefore be in conjunction; but being the other side of the sun, it would, of course, be a *superior* conjunction. At Q, the planet would appear in quadrature, and at M, in opposition, rising when the sun sets, like the full moon.

266. The superior planets, however, do not, like the inferior, undergo the same changes as the moon, but, with the exception of Mars, always present to the telescope their disks fully enlightened; for, if we viewed them from the sun, we should have the whole enlightened side turned constantly toward us; and so small is our own distance from the sun, compared with that of Jupiter, Saturn, or Uranus, that we view them nearly as though we stood on the sun. Mars, being nearer the earth, does in fact change his figure slightly; for, when seen in quadrature, at Q, a small part of the enlightened hemisphere is concealed from us, and the planet appears gibbous, like the moon when a little past the full. The superior planets, however, undergo considerable changes in apparent magnitude and brightness, being at one time much nearer to us than at another. Thus, in Fig. **111**, Mars, when at M, in opposition, is nearer the Earth than at M′, in superior conjunction, by the whole diameter of the earth's orbit—a space of about 190,000,000 miles. Hence, when this planet is in opposition, rising soon after the sun sets, it often surprises us by its unusual splendor, which appears more

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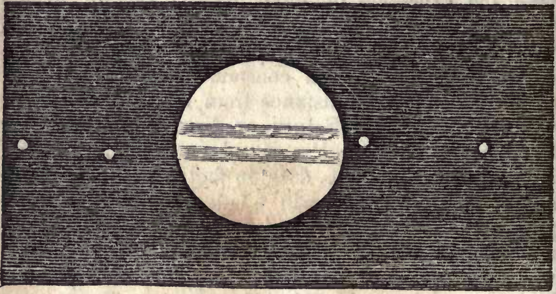
265. What are superior planets? How do they differ from the inferior? Explain their conjunction and opposition by the figure.

266. Have the superior planets any phases? What is said of the phases of Mars? What changes of apparent magnitude do the superior planets undergo? Explain the cause of these.

striking on account of its fiery red color. All the other planets, likewise, appear finest when in opposition, although the remoter planets are less altered than those that are nearer to us.

267. Jupiter is distinguished from all the other planets by his great magnitude. His diameter is 89,000 miles, and his volume 1281 times that of the earth. He revolves on his axis once in about ten hours, giving to places near his equator a motion twenty-seven times as swift as on the earth. It will be recollected, also, that the distance of Jupiter from the sun is 485,000,000 miles, and that his revolution around the sun occupies twelve years; so that every thing belonging to this planet is on a grand scale. The view of Jupiter through a good telescope, is one of the most splendid and interesting sights in astronomy. The disk expands into a large and bright orb, like the full moon; across the disk, arranged in parallel stripes, are several dusky bands, called *belts*; and

Fig. 112.



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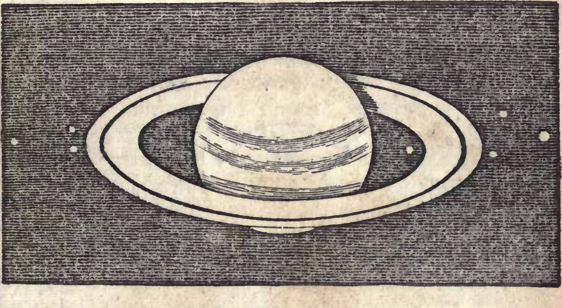
267. By what is Jupiter distinguished from all the other planets? His diameter—volume—distance from the sun? View of Jupiter through a good telescope? Appearance of his disk, belts, and satellites?

four bright satellites, or moons, constantly varying their positions, add another feature of peculiar magnificence.

268. Saturn has also within itself a system full of grandeur. Next to Jupiter, it is the largest of the planets, being 79,000 miles in diameter, or about 1000 times as large as the earth. It has, likewise, belts on its surface, though less distinct than those of Jupiter.

Fig. 113.



But the great peculiarity of Saturn is its *Ring*, a broad wheel, encompassing the planet at a great distance from it. What appears to be a single ring, when viewed with a small telescope, is found, when examined by powerful telescopes, to consist of two rings, separated from each other by a dark line of the sky, seen between them. Although the division of the rings appears to us, on account of our immense distance, as only a fine line, yet it is in reality an interval of not less than 1,800 miles; and, although we see in the telescope but a small speck of sky between the planet and the ring, yet it is really a space 20,000 miles broad. The

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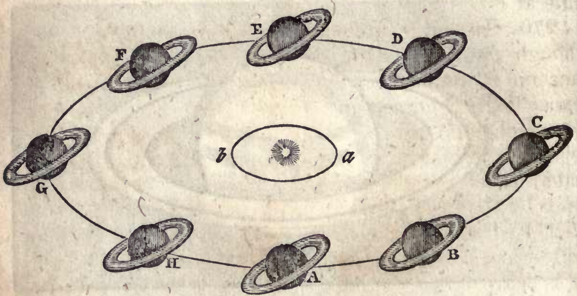
268. Saturn compared with Jupiter—diameter—volume—belts—*Ring*—what is said of this? Distance between the rings. Breadth

breadth of the inner wheel is 17,000 miles, and that of the outer, 10,500 miles ; so that the entire diameter of the outer ring, from outside to outside, is 179,000 miles. These rings are so far from the body of the planet, that an inhabitant of that world would not take them for appendages to his own planet, but would view them as magnificent arches on the face of the starry heavens.

Fig. 114.



269. Saturn's ring, in its revolution with the planet around the sun once in about thirty years, always keeps parallel to itself, as is represented in the annexed diagram, where the small circle, *a b*, is the earth's orbit, and Saturn is exhibited in eight different positions in his orbit. If we hold a circle, as a piece of coin, directly before the eye, we see the entire circle ; but if we hold it obliquely, it appears an ellipse ; and if we turn it round until we see it edgewise, the ellipse grows constantly narrower and narrower, until, when the edge is toward us, we see nothing but a line. If

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of each wheel. Entire diameter of the outer ring. What is said of the appearance of the rings from the planet ?

269. What position does the ring keep in its revolution around the sun ? Describe Fig 114. Into what figures is a circle projected

the learner obtains a clear idea of these appearances, he will easily understand the different appearances of Saturn's ring. In two points of the revolution around the sun, at A and E, the edge is presented to us, and we see the ring only as a fine line, or, perhaps, lose sight of it altogether. After passing this point, from B to C, we see more and more of the ellipse, until, in about seven years, it arrives at C, when it appears quite broad, as represented in figure 114. Then it gradually closes again for seven years more, and dwindles into a line at E.

270. Saturn is attended by seven ***satellites***. Although they are bodies of considerable size, yet, on account of their immense distance from us, they appear exceedingly minute, and require superior telescopes to see them at all. It is accounted a good telescope which will give a distinct view of even three of the satellites of Saturn, and the whole seven can be seen only by the most powerful telescopes in the world.

271. URANUS is also a large body, being 35,000 miles in diameter; but being 1800,000,000 miles off, it is scarcely seen except by the telescope, and would hardly be distinguished from a fixed star, if it were not seen to have the motions of a planet. In the most powerful telescopes, however, it exhibits more of the character of a planet. Herschel saw, as he supposed, six satellites belonging to this planet, but only two are commonly visible to the best telescopes. So distant is this planet, that the sun himself would appear from it 400 times less than he does to us, and it receives from him light and heat proportionally feeble.

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when seen in different positions? In what points is the edge presented to us? When does it appear broadest?

270. How many satellites has Saturn? How do they appear to the telescope? What power does it require to see them?

271. Uranus—his diameter—distance from the sun—appearance in the telescope—number of satellites. How would the sun appear from Uranus?

272. The NEW PLANETS, OR ASTEROIDS, Ceres, Pallas, Juno, and Vesta, were unknown until the commencement of the present century. They are so small as to be invisible to the naked eye, but are seen by telescopes of moderate power. They lie near together in the large space between the orbits of Mars and Jupiter, at an average distance from the sun of about 250,000,000 miles.

SEC. 4. *Of the Planetary Motions.*

273. The planets all revolve around the sun in the same direction, from west to east, and pursue nearly the same path in the heavens. Mercury wanders farthest from the general track, but he is never seen farther than about seven degrees from the ecliptic. The others, with the exception of the Asteroids, are always seen close in the neighborhood of the ecliptic, and we never need to look in any other part of the sky for a planet, than in the region of the sun's apparent path in the heavens.

274. If we could stand on the sun and view the planets move round it, their motions would appear very simple. We should see them, one after another, pursuing their way along the great highway of the heavens, the zodiac, rolling around the sun as the moon does around the earth, though with very different degrees of speed, those near the sun moving with far more rapidity than those more remote, often overtaking them, and passing rapidly by them. Mercury, especially, comes up with and passes Jupiter, Saturn, and Uranus, a great number of times while they are

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272. What is said of the New Planets—their discovery—size—position in the solar system—distance from the sun ?

273. Planetary motions—through what part of the heavens—which wanders farthest from the ecliptic ?

274. If we could view the planets from the sun, how would they appear to move ? In what orbits, and with what different degrees of speed ?

making their tardy circuit around the sun. To a spectator thus situated, the planets would all appear to move around him in great circles, such being their projections on the face of the sky. They are, however, not perfect circles, but are a little shorter in one direction than the other, forming an oval or ellipse.

275. Such would be the appearances of the planetary motions if viewed from the center of their motions, that is, at the sun, and such they are in fact. But two causes operate to make the motions of the planets appear very different from what they really are; first, we view them out of the center of their motions, and, secondly, we are ourselves in motion. We have seen, in the case of the inferior planets, Mercury and Venus, that our being out of the center makes them appear to run backward and forward across the sun, although they are all the while moving steadily on in one direction; and we know that our own motion along with the earth on its axis, every day, makes the heavens appear to move in the opposite direction. Hence, we see how very different may be the actual motions of the planets from what they appear to be. As we have said, they are actually very simple, moving steadily round the sun, all in one direction; but their apparent motions are exceedingly irregular. They sometimes move faster and sometimes slower —backward and forward—and at times appear to stand still for a considerable period.

276. If we have ever passed swiftly by a small vessel, sailing in the same direction with ourselves, but much slower, we may have seen the vessel appear to be moving backward, stern foremost. For a similar reason, the superior planets sometimes seem to move backward, merely because the earth has a swifter

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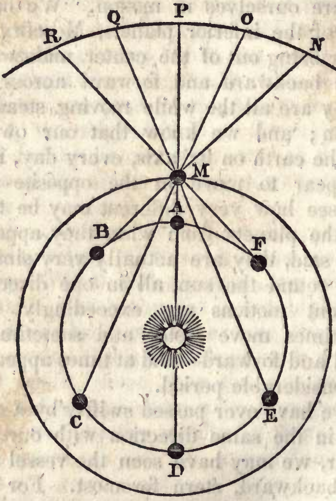
275. What makes the planetary motions appear very different from what they really are? Are the real motions more or less simple than the apparent?

motion, and sails rapidly by them. Then again they seem to stand still, because they are about turning, when our motion has ceased to carry them apparently backward any farther, and they are recovering their direct motion. They appear also to stand still, when they are moving directly toward us or from us, as Mercury or Venus does when near its greatest elongation. (See Fig. 109, page 238.) A diagram will assist us in obtaining a clear idea of the way in which these appearances are produced.

Fig. 115.



277. Let the inner circle, A B C, represent the earth's orbit, and the outer circle the orbit of Mars,

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276. Appearance of a vessel when we pass rapidly by it? Why do the superior planets appear to move backward, and to stand still?

(or any other superior planet,) and N R a portion of the concave sphere of the heavens. To make the case simple, we will suppose Mars to be stationary at M, in opposition; for, although he is actually moving eastward all the while, yet, since the earth is moving the same way more rapidly, their relative situations will be the same, if we suppose Mars to stand still and the earth to move on with the excess of its motion above that of the planet. As the earth moves from A to B, Mars appears to move backward from P to N; for the planet will always appear in the heavens in the direction of the straight line, as B M, drawn from the spectator to the body. When the earth is at B, Mars appears stationary, because the earth is moving directly from him, and the line B M N does not change its direction. But while the earth moves on to C, D, E, F, the planet resumes a direct motion eastward through O, P, Q, R. Here it again stands still, while the earth is moving directly toward it, and then goes backward again. When the planet is in opposition, the earth being at A, its motion appears more rapid than in other situations, because then it is nearest to us. In the superior conjunction, when the earth is at D, the motion of Mars is comparatively slow.

278. There are three great Laws that regulate the motions of all bodies belonging to the Solar System, called KEPLER's Laws, from the name of the great astronomer who discovered them. The first is, that *the orbits of the earth and all the planets are ellipses, having the sun in one of the foci of the ellipse.* Figure 116 represents such an ellipse, differing but little from a circle, but still having the diameter, A B, called the *major axis* of the orbit, perceptibly longer than C D. The

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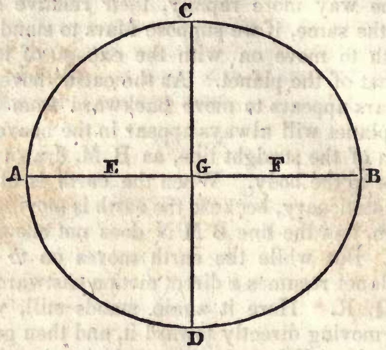
277. Illustrate the motion of Mars from Fig. 115. When is the motion most rapid? When slow?

278. Kepler's Laws. Repeat the first law. What is an ellipse—the major axis—foci—perihelion—aphelion?

two points, E and F, (being the points from which, by a certain process, the figure is described,) are called the two *foci*, and each of them, a *focus*, of the ellipse. Suppose the sun at F, then B will be the *perihelion* or nearest distance of a planet to the sun, and A is the *aphelion*, or farthest distance.

Fig. 116.



279. A line drawn from the sun to a planet is called the *radius vector*, as E *a* or E *b*, (Fig. 117;) and the second of Kepler's Laws is, that while a planet is going round the sun, *the radius vector passes over equal spaces in equal times*. The meaning of this is, that, if an imaginary line, as a cord, were extended from the sun to any planet, this cord would sweep over just as much space one day as another. When the planet is at its perihelion, the cord would, indeed, move faster than toward the aphelion; but it would also be shorter,

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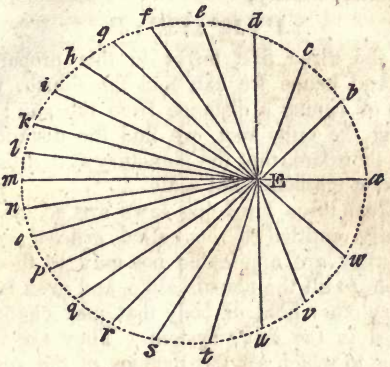
279. What is the radius vector? Repeat the second law. Explain its meaning.

and the greater breadth of the space, E *a b*, would make it just equal to the narrower but longer space, E *l m*. This law has been of incalculable service in all the higher investigations of astronomy.

Fig. 117.



280. The third of Kepler's Laws is, that *the squares of the periodic times of different planets, are proportioned to the cubes of the major axes of their orbits.* Now the periodic time of a planet, or the time it takes to go round the sun, from any star back to the same star again, can be seen by watching it, as has often been done, during the whole of its revolution. We also know the length of the major axis of the earth's orbit, because it is just twice the average or mean distance of the earth from the sun. These things being known, we can find the distance of any of the planets from the sun by a simple statement in the rule of three. For example, let it be required to find the major axis of Jupiter's orbit, or the

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280. Repeat the third law. What is meant by the periodic time of a planet? How may the periodic time be found? Do we know

mean distance of Jupiter from the sun, which is half the length of that axis. Then, since the earth's periodic time is one year, and Jupiter's twelve years, (putting E for the earth's distance from the sun, and J for Jupiter's,) we say,

$$1^2 : 12^2 : : E^3 : J^3.$$

Now the three first terms in this proportion are known, and hence we can find the fourth, which is the cube of Jupiter's distance from the sun; and, on extracting the cube root, we find the distance itself. We see, therefore, that the planetary system is laid off by an exact mathematical scale.

281. The three foregoing laws are so many great facts, fully entitled to be called *general principles*, because they are applicable not only to this or that planet, but to all the planets alike, and even to comets, and every other kind of body that may chance to be discovered in the solar system. They are the rules according to which all the motions of the system are performed. But there is a still higher inquiry, respecting the *causes* of the planetary motions, which aims at ascertaining not in *what manner* the planets move, but *why* they move at all, and by what *forces* their motions are produced and sustained. Sir Isaac Newton first discovered the great principle upon which all the motions of the heavenly bodies depend, that of *Universal Gravitation*. In its simplest expression it is nearly this: *all matter attracts all other matter*. But a more precise expression of the law of gravitation is as follows: *Every body in the universe, whether great or small, attracts every other body, with a force which is proportioned to*

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the major axis of the earth's orbit? How to find the major axis of Jupiter's orbit?

281. Why are these laws called general principles? What higher inquiry is there? Who first discovered the grand law of the celestial motions? What is it called? Its simplest expression. Its more precise expression

the quantity of matter directly, and to the square of the distance inversely.

282. This is the most comprehensive and important of all the laws of nature, and ought therefore to be clearly understood in its several parts. *First*, it asserts that *all matter* in the universe is subject to it. In this respect it differs from *Gravity*, which respects only the attraction exerted by the earth, and all bodies within the sphere of its influence. But Universal Gravitation embraces the whole solar system—sun, moon, planets, comets, and any other form of matter within the system. Nor does it stop here; it extends likewise to the stars, and comprehends the infinitude of worlds that lie in boundless space. *Secondly*, the law asserts that the attraction of gravitation is in proportion to the *quantity of matter*. Every body gives and receives of this mysterious influence an amount exactly proportioned to its weight; and hence all bodies exert an equal force on each other. The sun attracts the earth and the earth the sun, and one just as much as the other; for if the sun, in consequence of its having 354,000 times as much matter as the earth, exerts upon it 354,000 times as much force as it would do if it had the same weight with the earth, it also receives from the earth so much more in consequence of its greater weight. Were the sun divided into 354,000 bodies, each as heavy as the earth, every one would receive an equal share of the earth's attraction, and of course the whole would receive in the same degree as they imparted. *Thirdly*, the law asserts that, at different distances, the force of gravitation is *inversely as the square of the distance*. If a body is *twice* as far off, it attracts and is attracted four

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282. What is said of the importance of this law? What does it assert *first*—what *secondly*? How much does every body give and receive of this influence? Example in the earth and sun. What does the law assert *thirdly*? How much less does a body attract another when twice as far off, or ten times as far?

times less ; if *ten* times as far, one hundred times less ; if a *hundred* times as far, ten thousand times less.

283. This great principle, which has led to a knowledge of the causes of the celestial motions, and given us an insight into the machinery of the Universe, was discovered by Sir Isaac Newton, who is generally acknowledged to have had the most profound mind of any philosopher that has ever lived. He was born in a country town in England in the year 1642. He was a farmer's son, and his father having died before he was born, his friends designed him for a farmer ; but his strong and unconquerable passion for study, and the great mechanical genius he displayed in his boyhood, led them to the fortunate determination to educate him at the University.

284. But let us see how the principle of Gravitation is applied to explain the revolutions of the heavenly bodies. If I throw a stone horizontally, the attraction of the earth will continually draw it downwards, out of the line of direction in which it was thrown, and make it descend to the earth in a curve. The particular form of the curve will depend on the velocity with which it is thrown. It will always *begin* to move in the line of direction in which it is projected; but it will soon be turned from that line toward the earth. It will, however, continue nearer to the line of projection, in proportion as the velocity of projection is greater. Let A C (Fig. 118) be perpendicular to the horizon, and A B parallel to it, and let a stone be thrown from A in the direction of A B. It will, in every case, commence its motion in the line A B, which will therefore be a tangent to the curve it de-

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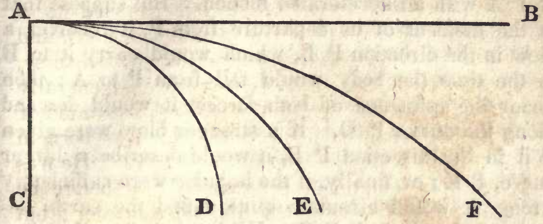
283. What is said of Sir Isaac Newton ?

284. How is the principle of universal gravitation applied to the explanation of the celestial motions ? How will a stone move when thrown horizontally ? Explain Fig. 118.

scribes; but, if it be thrown with a small velocity, it will soon depart from the tangent, describing the curve

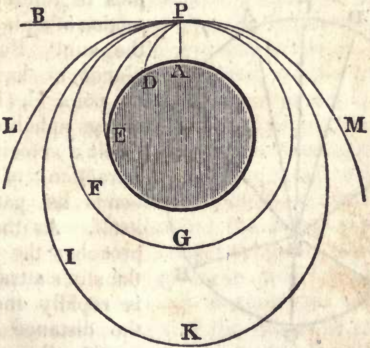
Fig. 118.



A D; with a greater velocity, it will describe a curve nearer the tangent, at A E; and with a still greater velocity, it will describe the curve A F.

285. As an example of a body revolving in an orbit under the influence of two forces, suppose a body

Fig. 119.



placed at any point, P, (Fig. 119,) above the surface of the earth, and let P A be the direction of the earth's

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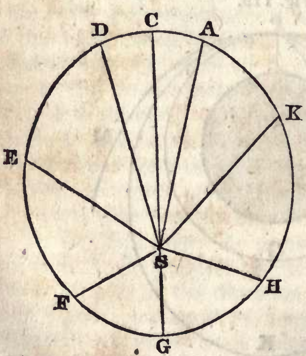
285. Explain the motions of a body from Fig. 119.

center, or a line perpendicular to the horizon. If the body were allowed to move, without receiving any impulse, it would descend to the earth in the direction of P A with an accelerated motion. But suppose that at the moment of its departure from P, it receives a blow in the direction P B, which would carry it to B in the time the body would fall from P to A; then under the influence of both forces, it would descend along the curve P D. If a stronger blow were given to it in the direction P B, it would describe a larger curve, P E; or, finally, if the impulse were sufficiently strong, it would circulate quite round the earth, describing the circle P F G. With a velocity of projection still greater, it would describe an ellipse, P I K; and if the velocity were increased to a certain degree, the figure would become a parabola, L P M,—a curve which never returns into itself.

Fig. 120.



286. Now let us consider the same principles in reference to the motion of a planet around the sun. Suppose the planet to have passed the point C, (Fig. 120,) at the aphelion, with so small a velocity, that the attraction of the sun bends its path toward itself. As the body approaches the sun, since the sun's attractive force is rapidly increased as the distance is diminished, the planet's motion is continually accelerated, and becomes very swift as it approaches nearer the sun. But, when a body is revolving in a curve, an increase of

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286. Explain the motions of a planet from Fig. 120.

velocity causes a rapid increase in the *centrifugal force,* and makes it endeavor with more and more force to fly off in the direction of a tangent to its orbit. Hence, the increase of velocity as it approaches the sun, will not carry it into the sun, but the more rapid increase of the centrifugal force will keep it off, and carry it by, and finally make it describe the remaining portion of the curve, back to the place where it set out. After it passes the perihelion, at G, the sun's attraction constantly operates to hold it back, and as it proceeds through H and K to A and C, it is like a ball rolled up hill, until finally its motion becomes so slow, that the centrifugal force yields to the force of attraction, and it turns about to renew the same circuit.

287. Since the nature of the curve which any planet describes depends on the proportion between the two forces, of projection and attraction, astronomers have inquired what proportion must have been observed when the planets were first launched into space, in order that they should have revolved in the orbits they have; and it is found that the forces were so adjusted as to make the centrifugal and attractive forces nearly equal, that of projection being a little greater. Had they been exactly equal, the curve would have been a circle; and had the force of projection been much greater than it was, the ellipses would have been much longer, and the whole system much more irregular. The planets also revolve on their axes at the same time that they revolve around the sun; and astronomers have inquired what must have been the nature of the impulses originally given, in order to have produced these two motions such as they are. If we strike a ball in the exact line of the center of gravity, it will move forward without turning on its axis; but if we

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287. How were the forces of projection and attraction adjusted to each other, when the planets were first launched into space? How strike it out of that direction we can make it move forward and turn on its axis at the same time. It is calculated that the earth must have received the impulse which gave to her her two motions, at a distance from the center equal to the $\frac{1}{165}$th part of the earth's radius. Such an impulse would suffice to give the two motions in question; but it would be presumptuous to undertake to assign the exact mode by which the Almighty first impressed upon the planetary system its harmonious movements; and all such expressions as "launching these bodies into space," or "impelling" them in certain directions, must be regarded as mere figures of speech.

288. Besides explaining the revolutions of the heavenly bodies, the principle of universal gravitation accounts for all their *irregularities*. Since every body in the solar system attracts every other, each is liable to be drawn out of its customary path, and all the bodies tend mutually to disturb each other's motions. Most of them are so far apart as to feel each other's influence but little; but in other cases, where any two bodies come far within each other's sphere of attraction, the mutual disturbance of their motions is very great. The moon, especially, has its motions continually disturbed by the attractive force of the sun. When the sun acts equally on the earth and the moon, as it does when the two bodies are at the same distance from him, he does not disturb their mutual relations; as the passengers on board a steamboat maintain the same position with respect to each other, whether the boat is going with or against the current. But, at new moon, the moon being nearer the sun than

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must they have been impelled in order to have the two motions? How must the earth have been struck?

288 Besides the revolutions of the heavenly bodies, for what else does the principle of universal gravitation account? How does the attraction of different bodies tend to affect each other's motions? What is said of the moon? When does the sun disturb the mutual relations

the earth is, is more attracted than the earth; and at full moon, the earth being nearer the sun than the moon is, is more attracted than the moon. Hence, in both cases, the sun tends to separate the two bodies. At other times, as when the moon is in quadrature, the influence of the sun tends to bring the bodies nearer together. Sometimes it causes the moon to move faster, and sometimes slower; so that owing to these various causes, the moon's motions are continually disturbed, which subjects her to so many irregularities, that it has required vast labor and research to ascertain the exact amount of each, and so to apply it as to assign the precise place of the moon in the heavens at any given time.

289. Among all the irregularities to which the heavenly bodies are subject, there is not one which the principle of universal gravitation does not account for, and even render necessary; so that if it had never been actually observed, a just consideration of the consequences of the operation of this principle, would authorize us to say that it must take place. Indeed, many of the known irregularities were first discovered by the aid of the doctrine of gravitation, and afterward verified by actual observation. Such a tendency of all the heavenly bodies to disturb each other's motions, might seem to threaten the safety of the whole system, and throw the whole into final disorder and ruin; but astronomers have shown, by the aid of this same principle, that all possible irregularities which can occur among the planets, have a narrow, definite limit—increasing first on one side, then on the other, and thus

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of the moon and earth? When does the sun attract the moon more than the earth? When the earth more than the moon? What various disturbances does it produce on the moon's motions?

289. Does the principle of universal gravitation account for the irregularities of the celestial motions? How were many of them first discovered? Will these irregularities produce disorder and ruin? What has been shown respecting their limit?

vibrating for ever about a mean value, which secures the stability of the universe.

CHAPTER VII.

COMETS.

DESCRIPTION—MAGNITUDE AND BRIGHTNESS—PERIODS—QUANTITY OF MATTER—MOTIONS—PREDICTION OF THEIR RETURNS—DANGERS.

290. NOTHING in astronomy is more truly admirable, than the knowledge which astronomers have acquired of the motions of comets, and the power they have gained of predicting their return. Indeed, every thing belonging to this class of bodies is so wonderful, as to seem rather a tale of romance than a simple recital of facts.

291. A comet, when perfectly formed, consists of three parts, the nucleus, the envelope, and the tail. The *nucleus*, or body of the comet, is usually distinguished by its forming a bright point in the center of the head, conveying the idea of a solid, or at least of a dense portion of matter. Though it is usually very small when compared with the other parts of the comet, and is sometimes wanting altogether, yet it occasionally is large enough to be measured by the aid of the telescope. The *envelope* (sometimes called the *coma*, from a Latin word signifying hair, in allusion to its hairy appearance,) is a thick, misty covering, that surrounds the head of the comet. Many comets have no nucleus, but present only a foggy mass. Indeed, there is a regular gradation of comets, from such as are composed merely of a gaseous or vapory medium, to those

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290. What is said of the knowledge astronomers have gained of comets?

291. Specify the several parts of a comet, and describe each part—

which have a well-defined nucleus. In some instances, astronomers have detected, with their telescopes, small stars through the densest part of the comet. The tail is regarded as an expansion or prolongation of the envelope, and presenting, as it sometimes does, a train of astonishing length, it confers on this class of bodies their peculiar celebrity. These several parts are exhibited in Fig. 121, which represents the appearance

Fig. 121.

of the celebrated comet of 1680, and which, in general size and shape, is not unlike that of 1843. The latter, however, was not so broad in proportion to its length, and its head (including the nucleus and coma) was far less conspicuous.

292. In *magnitude* and *brightness*, comets exhibit great diversity. History informs us of several comets so bright as to be distinctly visible in the daytime, even at noon, and in the brightest sunshine. Such was the comet seen at Rome a little before the assas-

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the nucleus—the envelope—the tail. How did the comet of 1680 compare with that of 1843?

292. What is said of the magnitude and brightness of comets? Of the comet seen at Rome? Of that of 1680? Of 1811? How

sination of Julius Cæsar; and, in a superstitious age, very naturally considered as the precursor of that event. The comet of 1680 covered an arc of the heavens of ninety-seven degrees, sufficient to reach from the setting sun to the zenith, and its length was estimated at 123,000,000 miles. The comet of 1811 had a nucleus only 428 miles in diameter, but a tail 132,000,000 miles long; and had it been coiled around the earth like a serpent, it would have reached round more than 5000 times. Other comets are exceedingly small, the nucleus being in one case estimated at only 25 miles; and some which are destitute of any perceptible nucleus, appear to the largest telescopes, even when nearest to us, only as a small speck of fog. The majority of comets can be seen only by the aid of the telescope. Indeed, the same comet has different appearances at its different returns. Halley's comet, in 1305, was described by the historians of that age as the comet of "horrific magnitude;" yet, in 1835, when it reappeared, the greatest length of its tail was only about twelve degrees, whereas that of the comet of 1843 was about forty degrees.

293. The *periods* of comets, in their revolutions around the sun, are equally various. Encke's comet, which has the shortest known period, completes its revolution in 3⅓ years; while that of 1811 is estimated to have a period of 3,383 years. The distances to which different comets recede from the sun are equally various. While Encke's comet performs its entire revolution within the orbit of Jupiter, Halley's comet recedes from the sun to twice the distance of Uranus, or 3600,000,000 miles. Some comets, indeed, are thought to go a much greater distance from the sun

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small are some comets? How does the same comet appear at its different returns?

293. What is said of the periods of the comets? Of Encke's comet? Of that of 1811? What of the distances to which they recede from the sun?

than this; while some are supposed to pass into curves, which do not, like the ellipse, return into themselves; and, in this case, they never come back to the sun.

294. Comets shine *by reflecting the light of the sun.* In one or two cases, they have been thought to exhibit distinct *phases*, like the moon, and experiments made on the light itself, indicate that it is reflected and not direct light. The tails of comets extend *in a direct line from the sun*, following the body as it approaches that luminary, and preceding the body as it recedes from it.

295. The *quantity of matter* in comets is exceedingly small. The tails consist of matter so light, that the smallest stars are visible through them. They can only be regarded as masses of thin vapor, susceptible of being penetrated through their whole substance by the sunbeams, and reflecting them alike from their interior parts and from their surfaces. "The highest clouds that float in our atmosphere," (says a great astronomer, Sir John Herschel,) "must be looked upon as dense and massive bodies compared with the filmy and all but spiritual texture of a comet." The small quantity of matter in comets is proved by the fact, that they have at times passed very near to some of the planets, without disturbing their motions in any appreciable degree. As the force of gravity is always proportioned to the quantity of matter, were the density of these bodies at all comparable to their size, on coming near one of the planets, they would raise enormous tides, and perhaps even draw the planet itself out of its orbit. But the comet of 1770, in its way to the sun, got entangled among the satellites of Jupiter, and remained near them four months; yet it

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294. By what light do comets shine? Do they ever exhibit phases? What is the direction of their tails?

295. Quantity of matter in comets? Extreme thinness? What proofs are stated to show their small quantity of matter? What is

did not perceptibly change their motions. The same comet also came very near to the earth; so that, had its quantity of matter been equal to that of the earth, it would, by its attraction, have caused the earth to have revolved in an orbit so much larger than at present, as to have increased the length of the year two hours and forty-seven minutes. Yet it produced no sensible effect on the length of the year. It may, indeed, be asked, what proof we have that comets have *any* matter, and are not mere reflexions of light? The answer is, that although they are not able, by their own force of attraction, to disturb the motions of the planets, yet they are themselves exceedingly disturbed by the action of the planets, and in exact conformity with the laws of universal gravitation. A delicate compass may be greatly agitated by the vicinity of a mass of iron, while the iron is not sensibly affected by the attraction of the needle.

296. The *motions* of comets are the most wonderful of all their phenomena. When they first come into view, at a great distance from the sun, as is sometimes the case, they make very slow approaches from day to day, and even, in some cases, advance but little from week to week. When, however, they come near to the sun, their velocity increases with prodigious rapidity, sometimes exceeding a million of miles an hour; they wheel around the sun like lightning; and recede again with a velocity which diminishes at the same rate as it before increased. We have seen that the planets move in orbits which are nearly circular, and that therefore they always keep at nearly the same distance from the sun. Not so with comets. Their perihelion distance is sometimes so small that they almost graze

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said of the comet of 1770? What proof have we that they contain any matter?

296. What is said of the motions of comets? What is the shape of their orbits? Of their distance from the sun at the perihelion

his surface, while their aphelion lies far beyond the utmost bounds of the planetary system, towards the region of the stars. This was the case with the comet of 1680, and the same is probably true of the wonderful comet of 1843. But irregular as are their motions, they are all performed in exact obedience to the great law of universal gravitation. The radius vector always passes over equal spaces in equal times; the greater length of the triangular space described at the aphelion, where the motion is so slow, being compensated by the greater breadth of the triangular space swept over at the perihelion, where the motion is so swift.

297. The appearances of the same comet at different periods of its return are so various, that we can never pronounce a given comet to be the same with one that has appeared before, from any peculiarities in its form, size, or color, since in all these respects it is very different at different returns; but it is judged to be the same if its *path* through the heavens, as traced among the stars, is the same. If, on comparing two comets that have appeared at different times, they both moved in orbits equally inclined to the ecliptic; if they crossed the ecliptic in the same place among the stars; if they came nearest the sun, or passed their perihelion, in the same part of the heavens; if their distance from the sun at that time was the same; and, finally, if they both moved in the same direction with regard to the signs, that is, both east, or both west; then we should pronounce them to be one and the same comet. But if they disagreed in more or less of these particulars, we should say that they were not the same but different bodies.

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and at their aphelion? Are the motions of a comet subject to the laws of gravitation?

297. How do we determine that a comet is the same with one that has appeared before? Enumerate the several particulars in which the two must agree?

298. Having established the identity of a comet with one that appeared at some previous period, the interval between the two periods would either be the time of its revolution, or some multiple or aliquot part of that time. Should we, for example, find a present comet to be identical with one that appeared 150 years ago, its period might be either 150 or 75 years, since possibly it might have returned to the sun twice in 150 years, although its intermediate return, at the end of 75 years, was either not observed or not recorded. Hence the method of *predicting* the return of a comet which has once appeared requires, first, that we ascertain with all possible accuracy the particulars enumerated in article 297, which are called the *elements* of the comet, and then compare these elements with those of other comets as recorded in works on this subject. The elements of about 130 comets have been found and registered in astronomical works, to serve for future comparison, but three only have their periodic times certainly determined. These are Halley's, Biela's, and Encke's comets; the first of which has a period of 75 or 76 years; the second, of $6\frac{3}{4}$ years; the third, of $3\frac{1}{3}$ years.

299. Halley's comet is the most interesting of these, and perhaps, on all accounts, the most interesting member of the solar system. It was the first whose return was predicted with success. Having appeared in 1682, Dr. Halley, a great English astronomer, then living, ascertained that its elements were the same with one that had appeared several times before, at intervals corresponding to about seventy-six years, and hence pronounced this to be its period, and predicted

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298. When the identity with a previous comet is established, how do we learn the time of its revolution? What is the method of predicting their return? Of how many comets have the elements been determined? How many have their periods certainly ascertained?

299. What is said of Halley's comet? What prevented Halley's fixing the exact moment of its return? What is said about weighing

that in about seventy-six years more, namely, the latter part of 1758 or the beginning of 1759, it would return. It did so, and came to its perihelion on the 13th of March, 1759. What prevented his fixing the exact moment, was the uncertainty which then existed with respect to the effects of the planets in disturbing its motions. Since, in passing down to the sun, it would have to cross the orbits of all the planets, and would come near to some of them, it was liable thus to be greatly retarded in its movements by the powerful attraction of these great bodies. Before the exact amount of this force could be estimated, the precise quantity of matter in those bodies must be known; that is, they must be *weighed*. This had been, at that time, imperfectly done. It has since been done with the greatest accuracy; such large bodies as Jupiter and Saturn have been weighed as truly and exactly as merchandise is weighed in scales. Hence, on the late return of Halley's comet, in 1835, the precise effect of all these disturbing forces was calculated, and the time of its return to the perihelion assigned to the very day.

300. The success of astronomers in this prediction was truly astonishing. During the greatest part of this long period of seventy-six years, the body had been wholly out of sight, beyond the planetary system, and beyond the reach of the largest telescopes. It must be followed through all this journey to the distance of 3600,000,000 of miles from the sun; and, before the precise time of its reappearance could be predicted, the amount of all the causes that could disturb its motions, arising from the various attractions of the planets, must be determined and applied. Since, moreover, these forces would vary with every variation of the

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the planets? How were the predictions respecting Halley's comet fulfilled in 1835?

300. What is said of the success of astronomers in this prediction?

distance, the calculation was to be made for every degree of the orbit, separately, through 360 degrees, for a period of seventy-six years. Guided, however, by such an unerring principle as universal gravitation, astronomers felt no doubt that the comet would be true to its appointed time, and they therefore told us, months beforehand, the time and manner of its first approach, and its subsequent progress. They told us that early in August, 1835, the comet would appear to the telescope as a dim speck of fog, at a certain hour of the night, in the northeast, not far from the seven stars; that it would slowly approach us, growing brighter and larger, until, in about a month, it would become visible to the naked eye; that, on the night of the 7th of October, it would approach the constellation of the Great Bear, and move along the northern sky through the seven bright stars of that constellation called the Dipper; that it would pass the sun about the middle of November, and reappear again on the other side of the sun about the end of December. All these predictions were verified, with a degree of exactness that constitutes this one of the highest achievements of science.

301. Since comets which approach very near the sun, like the comets of 1680 and 1843, cross the orbits of all the planets, in going to the sun and returning, the possibility that one of them may strike the earth has often been suggested, and at times created great alarm. It may quiet our apprehensions on this subject to reflect on the vast extent of the planetary spaces, in which these bodies are not crowded together as we see them erroneously represented in orreries and diagrams, but are sparsely scattered at immense distances from each other, resembling insects flying in the open

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Describe the difficulties attending it. What did astronomers tell us beforehand? How were these predictions fulfilled?

301. What is said of the danger that a comet will strike the earth?

heaven. Such a meeting with the earth is a very improbable event; and were it to happen, so extremely light is the matter of comets, that it would probably be stopped by the atmosphere; and if the matter is combustible, as we have some reason to think, it would probably be consumed without reaching the earth. And, finally, notwithstanding all the evils of which comets, in different ages of the world, have been considered as the harbingers, we have no reason to think that they ever did or ever will do the least injury to mankind.

CHAPTER VIII.

FIXED STARS.

NUMBER, CLASSIFICATION, AND DISTANCE OF THE STARS—DIFFERENT GROUPS AND VARIETIES—NATURE OF THE STARS, AND THE SYSTEM OF THE WORLD.

302. VAST as are the dimensions of the Solar System, to which our attention has hitherto been confined, it is but one among myriads of systems that compose the Universe. Every star is a world like this. The *fixed stars* are so called, because, to common observation, they always maintain the same situations with respect to each other. In order to obtain as clear and distinct ideas of them as we can, we will consider, under different heads, the number, classification, and distances of the stars—their various orders—their nature—and their arrangement in one grand system.

SEC. 1. *Of the Number, Classification, and Distances of the Stars.*

What would happen if it should? Have comets ever been known to do any injury?

302. Why are the fixed stars so called? Under what different heads are the fixed stars considered?

303. When we look at the firmament on a clear winter's night, the *number* of stars visible even to the naked eye, seems immense. But when we actually begin to count them, we are surprised to find the number so small. In some parts of the heavens, half a dozen stars will occupy a large tract of the sky, although in other parts they are more thickly crowded together. Hipparchus of Rhodes, in ancient times, first counted the stars, and stated their number at 1022. If we stand on the equator, where we can see both the northern and southern hemispheres, and carefully enumerate the stars that come into view at all seasons of the year, the entire number will amount to 3000. The telescope, however, brings to view hosts of stars invisible to the naked eye, the number increasing with every increase of power in the instrument; so that we may pronounce the number of stars that are actually distributed through the fields of space, to be literally endless. Single groups of half a dozen stars, as seen by the naked eye, often appear to a powerful telescope in the midst of hundreds of others of feebler light. Astronomers have actually registered the positions of no less than 50,000; and the whole number visible in the largest telescopes amounts to many millions.

304. The stars are *classed* by their apparent magnitudes. The whole number of magnitudes recorded is sixteen, of which the first six only are visible to the naked eye; the rest are *telescopic* stars. These magnitudes are not determined by any very definite scale, but are merely ranked according to their relative degrees of brightness, and this is left in a great measure to the judgment of the eye alone. The brightest stars,

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303. Apparent number of the stars on a general view. Result when we count them. Who first made a catalogue of the stars? How many were included? What is the greatest number visible to the naked eye? Numbers visible in the telescope? Whole number?

304. How are the stars classed? How many magnitudes? How many of them are visible to the naked eye? What are the rest called?

to the number of fifteen or twenty, are considered as stars of the first magnitude; the fifty or sixty next brightest, of the second magnitude; the next two hundred, of the third magnitude; and thus the number of each class increases rapidly, as we descend the scale, so that no less than fifteen or twenty thousand are included within the first seven magnitudes.

305. The stars have been grouped in *constellations* from the most remote antiquity. A few, as Orion, Bootes, and Ursa Major, (the Great Bear,) are mentioned in the most ancient writings, under the same names as they have at present. The names of the constellations are sometimes founded on a supposed resemblance to the objects to which those names belong; as the Swan and the Scorpion were evidently so denominated from their likeness to these animals. But, in most cases, it is impossible for us to find any reason for designating a constellation by the figure of the animal or hero which is employed to represent it. These representations were probably once connected with the fables of heathen mythology. The same figures, absurd as they appear, are still retained for the convenience of reference; since it is easy to find any particular star, by specifying the part of the figure to which it belongs; as when we say a star is in the *neck* of Taurus, in the *knee* of Hercules, or in the *tail* of the Great Bear. This method furnishes a general clew to their position; but the stars belonging to any individual constellation, are distinguished according to their apparent magnitudes, as follows: First, by the Greek letters, Alpha, Beta, Gamma, &c. Thus, *Alpha*, of Orion, denotes the largest star in that constellation;

How many stars of the first magnitude? How many of the second? Of the third? How many within the first seven?

305. What is said of the antiquity of the constellations? Origin of their names? Why are the ancient figures retained? How are the individual stars of a constellation denoted?

Beta, of Andromeda, the second star in that; and *Gamma*, of the Lion, the third brightest star in the Lion. When the number of the Greek letters is insufficient, recourse is had to the letters of the Roman alphabet, a, b, c, &c.; and in all cases where these are exhausted, the final resort is to numbers. This will evidently at length become necessary, since the largest constellations contain many hundreds or even thousands of stars.

306. When we look at the firmament on a clear Autumnal or Winter evening, it appears so thickly set with stars, that one would perhaps imagine, that the task of learning even the brightest of them would be almost hopeless. So far is this from the truth, that it is a very easy task to become acquainted with the names and positions of the stars of the first magnitude, and of the leading constellations. It is but, at first, to obtain the assistance of an instructor, or some friend who is familiar with the stars, just to point out a few of the most conspicuous constellations. A few of the largest stars in it will serve to distinguish a constellation, and enable us to recognise it. These we may learn first, and afterward fill up the group by finding its smaller members. Thus we may at first content ourselves with learning to recognise the Great Bear, by the seven bright stars called the *Dipper;* and we might afterward return to this constellation, and learn to trace out the head, the feet, and other parts of the animal. Having learned to recognise the most noted of the constellations, so as to know them the instant we see them anywhere in the sky, we may then learn the names and positions of a few single stars of special celebrity, as *Sirius*, (the Dog-Star,) the brightest of all the fixed stars, situated in the constellation Canis Ma-

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306. Is it a difficult task to learn the constellations, and the names of the largest stars? What directions are given?

jor, (the Greater Dog;) *Aldebaran*, in Taurus; *Arcturus*, in Bootes; *Antares*, in the Scorpion; *Capella*, in the Wagoner.

307. It is a pleasant evening recreation for a small company of young astronomers to go out together, and learn one or two constellations every favorable evening, until the whole are mastered. A map of the stars, placed where the company can easily resort to it, will, by a little practice, enable them to find the relative situations of the stars, with as much ease as they find those of places on the map of any country. A celestial globe, when it can be procured, is better still; for it may be so *rectified* as to represent the exact appearance of the heavens on any particular evening. It will be advisable to learn first the constellations of the zodiac, which have the same names as the signs of the zodiac enumerated in Article 203, (Aries, Taurus, Gemini, &c.;) although any order may be pursued that suits the season of the year. The most brilliant constellations are in the evening sky in the Winter.*

308. Great difficulties have attended the attempt to measure the *distances* of the fixed stars. We must here call to mind the manner in which the distances of nearer bodies, as the moon and the sun, are ascertained, by means of parallax. The moon, for example, is at the same moment projected on different points of the sky, by spectators viewing her at places on the earth at a distance from each other. (See Art. 218.) By means of this apparent change of place in the moon, when viewed from different places, astron-

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* For more particular directions for studying the constellations, including a description of the most important of them, the author begs leave to refer to his larger books, as the "School Astronomy," and "Letters on Astronomy."

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307. What is proposed as an evening's recreation? What use is to be made of a celestial map or globe? With what constellations is it advisable to commence?

308. What is said of the attempt to measure the distances of the

omers, as already explained, derive her horizontal parallax, and from that her distance from the center of the earth. The stars, however, are so far off, that they have no horizontal parallax, but appear always in the same direction, whether viewed from one part of the earth or another. They have not, indeed, until very recently, appeared to have any *annual parallax;* by which is meant, that they do not shift their places in the least in consequence of our viewing them at different extremities of the earth's orbit,—a distance of 190,000,000 of miles. The earth, in its annual revolution around the sun, must be so much nearer to certain stars that lie on one side of her orbit, than she is to the same stars when on the opposite side of her orbit; and yet even this immense change in the place of the spectator, makes no apparent change in the position of the stars of the first magnitude; which, from their being so conspicuous, were naturally inferred to be nearest to us. Although this result does not tell us how far off the stars actually are, yet it shows us that they cannot be within a distance of twenty millions of millions of miles; for were they within that distance, the nicest observations would detect in them *some* annual parallax. If these conclusions are drawn with respect to the largest of the fixed stars, which we suppose to be vastly nearer to us than those of the smallest magnitude, the idea of distance swells upon us when we attempt to estimate the remoteness of the latter. Of some stars it is said, that thousands of years would be required for their light to travel down to us.

309. By some recent observations, however, it is supposed that the long sought for parallax among the fixed stars has been discovered. In the year 1838,

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fixed stars? Have the stars in general any horizontal parallax? What is meant by saying that the stars have no annual parallax? Beyond what distance must the great body of the stars be?

Professor Bessel, of Koningsberg, (Prussia,) announced the discovery of a parallax in one of the stars of the constellation Swan, (61 *Cygni,*) amounting to about *one third of a second.* This seems, indeed, so small an angle, that we might have reason to suspect the reality of the determination; but the most competent judges, who have thoroughly examined the process by which the discovery was made, give their assent to it. What, then, do astronomers understand when they say, that a parallax has been discovered in one of the fixed stars, amounting to one-third of a second? They mean that the star in question apparently shifts its place in the heavens to that amount, when viewed at opposite extremities of the earth's orbit; namely, at points in space distant from each other 190,000,000 of miles. Let us reflect how small an arc of the heavens is one-third of a second! The angular breadth of the sun is but small, yet this is toward six thousand times as great as the discovered parallax. On calculating the *distance* of the star from us, by this means, it is found to be six hundred and fifty-seven thousand seven hundred times ninety-five millions of miles,—a distance which it would take light more than ten years to traverse.

SEC. 2. *Of Groups and Varieties of Stars.*

310. Under this head, we may consider Double, Temporary, and Variable Stars; Clusters and Nebulæ. *Double Stars* are those which appear single to the naked eye, but are resolved into two by the telescope; or, if not visible to the naked eye, they are such as,

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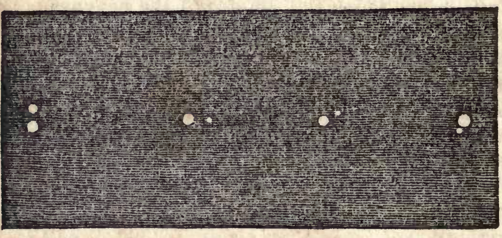
309. Give an account of the discovery of the parallax of 61 Cygni. How much is it? What do astronomers understand by this? How much less angular breadth is one-third of a second than the breadth of the sun? What distance does this imply?

310. Enumerate the different groups and varieties of the stars.

when seen in the telescope, are so close together as to be regarded as objects of this class. Sometimes, three or more stars are found in this near connection, constituting triple or multiple stars. Castor, for example, (one of the two bright stars in the constellation Gemini,) when seen by the naked eye, appears as a single star; but in a telescope, even of moderate power, it is resolved into two. These are nearly of equal size; but, more commonly, one is exceedingly small in comparison with the other, resembling a satellite near its primary, although in distance, in light, and in other characteristics, each has all the attributes of a star, and the combination, therefore, cannot be that of a star with a planetary satellite. The diagram shows four double stars, as they appear in large telescopes.

Fig. 122.



311. A circumstance which has given great interest to the double stars is, the recent discovery that some of them *revolve around each other*. Their times of revolution are very different, varying in the case of those already ascertained, from 43 to 1000 years, or more. The revolutions of these stars have revealed to us this most interesting fact, that *the law of gravitation*

What are double stars? Give an example in Castor. Why may not the smaller star be a planetary satellite?

extends to the fixed stars. Before these discoveries, we could not decide, except by a feeble analogy, that this law extended beyond the bounds of the solar system. Indeed, our belief rested more upon our idea of unity of design in the works of the Creator, than upon any certain proof; but the revolution of one star around another, in obedience to forces which are proved to be similar to those which govern the solar system, establishes the grand conclusion, that the law of gravitation is truly the law of the material universe.

312. *Temporary Stars* are new stars, which have appeared suddenly in the firmament, and after a certain interval, as suddenly disappeared, and returned no more. It was the appearance of a new star of this kind, one hundred and twenty-five years before the Christian era, that prompted Hipparchus to draw up a catalogue of the stars, so that future astronomers might be able to decide the question, whether the starry heavens are unchangeable or not. Such, also, was the star which suddenly shone out in the year 389, in the constellation Eagle, as bright as Venus, and after remaining three weeks, disappeared entirely. In 1572, a new star suddenly appeared, as bright as Sirius, and continued to increase until it surpassed Jupiter when brightest, and was visible at mid-day. In a month, it began to diminish; and, in three weeks afterward, it entirely disappeared. It is also found that stars are now missing, which were inserted in ancient catalogues, as then existing in the heavens.

313. *Variable Stars* are those which undergo a periodical change of brightness. One of these is the star *Mira*, in the whale. It appears once in eleven

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311. What has recently given great interest to the double stars? What inference is made respecting the law of gravitation?

312. What are temporary stars? What led Hipparchus to number the stars? What is said of the star of 389? Of 1572? What stars are now missing?

months, remains at its greatest brightness about a fortnight, being then equal to a star of the second magnitude. It then decreases about three months, until it becomes completely invisible, and remains so about five months, when it again becomes visible, and continues increasing during the remaining three months of its period. Another variable star in Perseus, goes through a great variety of changes in the course of three days. Others require many years to accomplish the period of their changes.

314. *Clusters* of stars will next claim our attention. In various parts of the sky, in a clear night, are seen large groups which, either by the naked eye, or by the aid of the smallest telescope, are perceived to consist of a great number of small stars. Such are the Pleiades, Coma Berenices, (Berenice's Hair,) and Præsepe, or the Beehive, in Cancer. The *Pleiades*, or Seven Stars, as they are called, in the neck of Taurus, is the most conspicuous cluster. With the naked eye, we do not distinguish more than six stars in this group; but the telescope exhibits fifty or sixty stars, crowded together, and apparently separated from the other parts of the starry heavens. *Berenice's Hair*, which may be seen in the summer sky in the west, a little westward of Arcturus, has fewer stars, but they are of a larger class than those which compose the Pleiades. The *Beehive*, or Nebula of Cancer, as it is called, is one of the finest objects of this kind for a small telescope. A common spy-glass, indeed, is sufficient to resolve it into separate stars. It is easily found, appearing to the naked eye somewhat hazy, like a comet, the stars being so near together that their light becomes blended. A reference to a celestial map or globe will show its exact position in the con-

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313. What are variable stars? Give an example in Mira, and in Perseus.

314. What is said of clusters of stars? Give examples. What is

stellation Cancer, and it will well repay those who can command a telescope of any size, for the trouble of looking it up. A similar cluster in the sword handle of Perseus, near the well-known object, Cassiopea's Chair, in the northern sky, also presents a very beautiful appearance to the telescope.

315. *Nebulæ* are faint, misty appearances, which are dimly seen among the stars, resembling comets, or a speck of fog. A few are visible to the naked eye; one, especially, in the girdle of the constellation Andromeda, which has often been reported as a newly discovered comet. The greater part, however, are visible only to telescopes of greater or less power. They are usually resolved by the telescope into myriads of small stars; though, in some instances, no powers of the telescope have been found sufficient to resolve them. The Galaxy, or Milky Way, presents a continual succession of large nebulæ. The great English astronomer, Sir William Herschel, has given catalogues of 2,000 nebulæ, and has shown that nebulous matter is distributed through the immensity of space in quantities inconceivably great, and in separate parcels of all shapes and sizes, and of all degrees of brightness, between a mere milky veil and the condensed light of a fixed star. In fact, more distinct nebulæ have been hunted out by the aid of telescopes, than the whole number of stars visible to the naked eye in a clear winter's night. Their appearances are extremely diversified. In many of them we can easily distinguish the individual stars; in those apparently more remote, the interval between the stars diminishes, until it becomes quite imperceptible; and

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said of the Pleiades? What of Berenice's Hair? What of the Bee-hive? Of the cluster in Perseus?

315. What are Nebulæ? Are any visible to the naked eye? How do they appear by the telescope? What is said of the Galaxy or Milky Way? How many nebulæ did Herschel discover? Can we

in their faintest aspect they dwindle to points so minute, as to be appropriately called *star dust.* Beyond this, no stars are distinctly visible, but only streaks or patches of milky light. In objects so distant as these assemblages of stars, any apparent interval between them must imply an immense distance; and were we to take our station in the midst of them, a firmament would expand itself over our heads like that of our evening sky, only a thousand times more rich and splendid; and were we to take our view from such a distant part of the universe, it is thought by astronomers that our own starry heavens would all melt together into the same soft and mysterious light, and be seen as a faint nebula on the utmost verge of creation.

316. Many of the nebulæ exhibit a tendency toward a globular form, and indicate a rapid condensation toward the center. These wonderful objects, however, are not confined to any particular form, but exhibit great varieties of figure. Sometimes they appear of an oval form; sometimes they are shaped like a fan; and the unresolvable kind often assume the most fantastic forms. But, since objects of this kind must be seen before they can be fully understood, it is hoped the learner will avail himself of any opportunity he may have to contemplate them through the telescope. Some of them are of astonishing dimensions. It is but little to say of many a nebula, that it would more than cover the whole solar system, embracing within it the immense orbit of Uranus.

SEC. 3. *Of the Nature of the Stars, and the System of the World.*

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resolve them all into stars? If we were to take our position in the midst of a great nebula, what should we see over our heads? How would our firmament appear?

316. What is said of the different forms of nebulæ? What of their dimensions?

317. We have seen that the stars are so distant, that not only would the earth dwindle to a point, and entirely vanish as seen from the nearest of them, but that the sun itself would appear only as a distant star, less brilliant than many of the stars appear to us. The diameter of the orbit of Uranus, which is about 3600,000,000 of miles, would, as seen from the nearest star, appear so small that the finest hair would more than cover it. The telescope itself, seems to lose all power when applied to measure the magnitudes of the stars; for although it may greatly increase their light, so as to make them dazzle the eye like the sun, yet it makes them no larger. They are still shining *points*. We may bring them, in effect, 6000 times nearer, and yet they are still too distant to appear otherwise than points. It would, therefore, seem fruitless to inquire into the nature of bodies so far from us, and which reveal themselves to us only as shining points in space. Still there are a few very satisfactory inferences that can be made out respecting them.

318. First, *the fixed stars are bodies greater than our earth.* Were the stars no larger than the earth, it would follow, on optical principles, that they could not be seen at such a distance as they are. Attempts have been made to estimate the comparative magnitudes of the brightest of the fixed stars, from the light which they afford. Knowing the rate at which the intensity of light decreases as the distance increases, we can find how far the sun must be removed from us, in order to appear no brighter than Sirius. The distance is found to be 140,000 times its present distance. But Sirius is more than 200,000 times as far off as the sun; hence it is inferred, that it must, upon the lowest estimate, give out twice as much light as the sun; or

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317. How would our sun appear from the nearest fixed star? How broad would the orbit of Uranus appear?

318. What is said of the size of the stars? Are the stars of various

that, in point of splendor, Sirius must be at least equal to two suns. Indeed, it is thought that its light equals that of fourteen suns. There is reason, however, to believe, that the stars are actually of various magnitudes, and that their apparent difference is not owing, as some have supposed, merely to their different distances. The two members of the double star in the Swan, (61 *Cygni*,) the motion of one of which has led to the discovery of a parallax, (see Art. 309,) are severally thought to have less than half the quantity of matter in the sun, which accounts for their appearing so diminutive in size, while they are apparently so much nearer to us than the great body of the stars.

319. Secondly, *the fixed stars are Suns*. It is inferred that they shine by their own light, and not like the planets, by reflected light, since reflected light would be too feeble to render them visible at such a distance. Moreover, it can be ascertained by applying certain tests to light itself, whether it is direct or reflected light; and the light of the stars, when thus examined, proves to be direct. Since, then, the stars are large bodies like the sun; since they are immensely farther off than the farthest planet; since they shine by their own light; and, in short, since their appearance is, in all respects, the same as the sun would exhibit if removed to the region of the stars, the conclusion is unavoidable that the stars are suns. We are justified, therefore, by sound analogy, in concluding that the stars were made for the same end as the sun; namely, as the centers of attraction to other planetary worlds, to which they severally afford light and heat. The chief purpose of the stars could not have been to adorn the firmament, or to give light by night, since by far the greater part of them are invisible to

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magnitudes? How large are the two members of the double star 61 Cygni?

319. How is it shown that the stars are suns? For what were they

the naked eye; nor as landmarks to the navigator, for only a small portion of them are adapted to this purpose; nor, finally, to influence the earth by their attractions, since their distance renders such an effect entirely insensible. If they are suns, and if they exert no important agencies upon our world, but are bodies evidently adapted to the same purpose as our sun, then it is as rational to suppose that they were made to give light and heat, as that the eye was made for seeing and the ear for hearing.

320. We are thus irresistibly led to the conclusion, that each star is a world within itself,—a sun, attended, like our sun, by planets to which it dispenses light and heat, and whose motions it controls by its attraction. Moreover, since we see all things on earth contrived in reference to the sustenance, safety, and happiness of man,—the light for his eyes, the air for his lungs, the heat to warm him, and to perform his labors by its mechanical and chemical agencies; since we see the earth yielding her flowers and fruits for his support, and the waters flowing to quench his thirst, or to bear his ships, and all the animal tribes subjected to his dominion; and, finally, since we see the sun himself endued with such powers, and placed at just such a distance from him, as to secure his safety and minister in the highest possible degree to his happiness; we are left in no doubt that this world was made for the dwelling place of man. But, on looking upward at the other planets, when we see other worlds resembling this in many respects, enlightened and regulated by the same sun, several of them much larger than the earth, furnishing a more ample space for intelligent beings, and fitted up with a greater number of moons

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made? Might it not have been to give light by night—to afford landmarks to the navigator—or to exert a power of attraction on the earth?

320. To what conclusion are we thus led? For what end were the stars made?

to give them light by night, we can hardly resist the conclusion that they, too, are intended as the abodes of intelligent, conscious beings, and are not mere solitary wastes. Finally, the same train of reasoning conducts us to the conclusion, that each star is a solar system, and that the universe is composed of worlds inhabited by different orders of intelligent beings.

321. It only remains to inquire respecting the *System of the World*, or to see in what order the various bodies that compose the universe are arranged. One thing is apparent to all who have studied the laws of nature,—that great *uniformity of plan* attends every department of the works of creation. A drop of water has the same constitution as the ocean ; a nut-shell of air, the same as the whole atmosphere. The nests and the eggs of a particular species of birds are the same in all ages ; the anatomy of man is so uniform, that the mechanism of one body is that of the race. A similar uniformity pervades the mechanism of the heavens. To begin with the bodies nearest to us, we see the earth attended by a satellite, the moon, that revolves about her in exact obedience to the law of universal gravitation. Since the discovery of the telescope has enabled us to see into the mechanism of the other planets, we see that Jupiter, Saturn, and Uranus, have each a more numerous retinue, but all still fashioned according to the same model, and obedient to the same law. The recent discovery of the revolution of one member of a double star around the other, shows that the same organization extends to the stars ; and certain motions of our own sun and his attendant worlds, indicate that our system is likewise slowly revolving around some other system. In each of the clusters of stars and nebulæ, we also see a mul-

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321. What is said of the uniformity of plan visible in the works of nature ? Show that a similar uniformity prevails in the general plan of the celestial bodies. How is this exemplified in the systems of Jupiter, Saturn, and Uranus ? In the revolutions of double stars ? What

titude of stars assembled together into one group; and, although we have not yet been able to detect a common system of motions of revolution among them, and on account of their immense distance, particularly of the nebulæ, perhaps we never shall be able, yet this very grouping indicates a mutual relation, and the symmetrical forms which many of them exhibit, prove an organization for some common end. Now such is the uniformity of the plan of creation, that where we have discovered what the plan is in the objects nearest to us, we may justly infer that it is the same in similar objects, however remote. Upon the strength of a sound analogy, therefore, we infer revolutions of the bodies composing the most distant nebulæ, similar to those which we see prevail among all nearer worlds.

322. This argument is strengthened and its truth rendered almost necessary, by the fact that without such motions of revolution, the various bodies of the universe would have a tendency to fall into disorder and ruin. By their mutual attractions, they would all tend directly toward each other, moving at first, indeed, with extreme slowness, but in the lapse of ages, with accelerated velocity, until they finally rushed together in the common center of gravity. We can conceive of no way in which such a consequence could be avoided, except that by which it is obviated in the systems which are subject to our observation, namely, by a projectile force impressed upon each body, which makes it constantly tend to move directly forward in a straight line, but which, when combined with the force of gravity existing mutually in all the bodies of the system, gives them harmonious revolutions around each other.

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indications of systematic arrangement do we see in the clusters and nebulæ?

322. What would happen to the various bodies in the universe without such revolutions? How could such a consequence be avoided?

323. We see, then, in the subordinate members of the solar system, in the earth and its moon, in Jupiter, Saturn, and Uranus, with their moons, a *type* of the mechanism of the world, and we conclude that the material universe is one great system; that the combination of planets with their satellites, constitutes the first or lowest order of worlds; that, next to these, planets are linked to suns; that these are bound to other suns, composing a still higher order in the scale of being; and, finally, that all the different systems of worlds move around their common center of gravity.

324. The view which the foregoing considerations present to us of the grandeur of the material universe, is almost overwhelming; and we can hardly avoid joining in the exclamations that have been uttered, after the same survey, upon the insignificant place which we occupy in the scale of being, nor cease to wonder, with Addison, that we are not lost among the infinitude of the works of God. It is cause of devout thankfulness, however, that omniscience and benevolence are at the helm of the universe; that the same hand which fashioned these innumerable worlds, and put them in motion, still directs them in their least as well as in their greatest phenomena; and that, if such a view as we have taken of the power of the Creator, fills us with awe and fear, the displays of care manifested in all his works for each of the lowest of his creatures, no less than for worlds and systems of worlds, should conspire with what we know of his works of Providence and Grace, to fill us with love and adoration.

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323. Describe the system of the world.

324. What is said of the grandeur of these views? What is special cause of thankfulness? How should the contemplation of the subject affect us?